Introduction

This report we hope will:

- give you a complete introduction to air assisted spraying.
- inform you about the results and experiences farmers and researchers have achieved with TWIN sprayers.

HARDI attaches great pride to the well-grounded research documentation that has been collated to form the main structure of this TWIN BOOK. We warmly acknowledge the contribution of independent researchers and advisory bodies who have invested in this development. However, the use of air assistance is not unique to HARDI´s TWIN SYSTEM, for many manufacturers seek to use similar features. The resulting commercial range of air assisted sprayers vary widely both in engineering, design and performance.
Several principles are sometimes available and test results have been derived with the TWIN that are attached to these other types of sprayers. We would like to assure you that the selection of results that follow in this TWIN BOOK have been achieved with the TWIN and are most likely to be unique to it. The TWIN SYSTEM remains the only air assisted sprayer which can truly entrain sprayed drops to apply them with predetermined velocity and approach angles. This patented underlying principle is your path to enhanced sprayer and pesticide performance.

HARDI INTERNATIONAL A/S

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TWIN BOOK

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Crop index

Conclusion after 10 years on the market

The Twin sprayer has all through the last 10 years demonstrated its advantages. Feed-back comments from world wide users can be clustered into three main groups.

1. **More economical plant protection.**
2. **More freedom to spray at the right time.**
3. **Less pollution of the surrounding environment.**

Farmers have achieved with the Twin:
- reduced consumption of pesticides (-16 % on average) compared to conventional spraying.
- 100 % higher field work rate.

These real benefits to the user are the result of the combination of many advances which Twin air assistance has, and continues to offer, beyond that achievable from the highest standard of conventional spraying.
It is these true technical advances that are now individually described.

1. Economical benefits

CONCLUSION

A TWIN sprayer can justify the higher investment with the following benefits:

- increased field work rates / less time needed to complete the job
- lower water rates and less downtime for filling
- real chemical savings
- better timing / more spraying hours available per day
- higher field efficacy for each spraying
- the exacting demands of both speciality and traditional crops can be met with one sprayer.

Calculated examples for 185, 370 and 741 acre farm units and 3 chosen sprayer sizes show that the extra investment in a TWIN sprayer can be economical already at a chemical saving of 7 % **(Table 1.)**.
This figure is of course sensitive to the type and size of farm in question - some conditions will be even more favorable for TWIN and in other cases, especially for small farms with traditional crops, a TWIN normally cannot be justified just looking at the pure economical benefits.

If a farmer reduces his chemical use an average of 16% due to TWIN, 9% of the savings can be added to his net-profit. Furthermore the spraying can be done in only half the number of days otherwise necessary for a conventional sprayer to do the job.

***Table 1** shows how many days are needed to spray 3 different farm sizes depending on the type of sprayer. Also the minimum chemical savings to make the investment in air profitable and average net savings are shown.*

Farm size	185 acres		370 acres		740 acres	
Sprayer size	40’, 264 gal., mounted		60’, 317 gal., mounted		80’, 580 gal., trailer	
Sprayer type	TWIN (TWIN STREAM)	Conventional (MASTER)	TWIN (TWIN SYSTEM)	Conventional (MEGA)	TWIN (TWIN FORCE)	Conventional (COMMANDER MHY)
Number of days needed for the spray job	8	19	16	39	25	59 *)
Pesticide savings necessary to pay the price difference for TWIN	5.3%		6.9%		7.3%	
Net. Pesticide savings with TWIN**	10.7%		9.1%		8.7%	

*) 59 days available for spraying is seldom realistic, it could therefore be argued that the TWIN should be compared with a conventional sprayer with larger tank and boom size

**) User surveys show the average chemical saving with TWIN is 16% compared to conventional spraying.

For the operational conditions for the calculations in **Table 1**, see **Note 1** and **Note 2** (page 38-40).

Other reasons for buying TWIN

There are great differences in how much importance farmers associate with reduced chemical dose rates: livestock farmers for instance who traditionally have problems getting the spray job done on time, or vegetable and potato growers for whom timing in itself is extremely important. Both agree that the greatest advantages of a TWIN sprayer are the high field work rates and low sensitivity to wind, with the benefits of a better biological efficacy being secondary.

In Netherlands the Ministry of Agriculture supports the farmers investment in air assisted spraying equipment with a 20 % subsidy on the retail price plus the freedom to write off 100 % in the first year if the farmer wants.

1.1. Less unwanted impact on surroundings

High field work rates and less dependency on wind speeds will allow spraying at the right time, when the pest is most sensitive to even a very low dose rate. Less drift and lower chemical consumption reduces potential negative side effects on the environment and human safety; there will be less exposure to pesticide in downwind water, on sprayed or adjacent downwind crops.
Also the soil deposit can be reduced as shown in **Figure 19 -** the increased on-plant deposit simply leaves less to be lost on the ground.

1.2. High spraying capacity

CONCLUSION

Because of more spraying hours available per day, lower water quantities and less down time for filling a TWIN sprayer will normally have at least double capacity in acres/season compared to a conventional sprayer **(Table 2)**. This means of course that an air assisted sprayer can cope with a larger farm size or a TWIN sprayer can do the job of 2 conventional sprayers on large farms.
If also taking advantage of the fact that the new developed TWIN FORCE sprayers are made to drive faster without increasing the wind drift, and the speed is increased from 4 to 10 mph, spraying capacity will all together triple compared to a conventional sprayer with same tank and boom size.

More spraying hours/day
Higher driving speed
Lower water quantities
Less down time for water filling

→ Higher spraying capacity

Spraying capacity - examples

From **Table 2** you can see how many acres can be treated per hour with 5 different sprayer models under the conditions specified below the table.

Table 2. *Sprayer capacity - acres per hour and acres per season - at 4 mph respectively 10 mph. Also maximum farm size (specified conditions) is shown for 5 different sprayers.*

	Capacity ac./hour*		ac./season		Farm size ac.	
Driving speed	4 mph	10 mph	4 mph	(10 mph)	4 mph	(10 mph)
MA 270 gal./ 40' HYB	12,8	-	1747		437 ac.	
CM 750 gal./ 80' OLH	22.2	-	3025		756 ac.	
MAA 270 gal./ 40' HAL**	14.6	-	4272		1068 ac.	
CM 580 gal./ 60' HAY**	21.0	33.9	6009	(9919)	1502 ac.	(2481 ac.)
CM 750 gal./ 80' HAZ**	25.2	40.0	7458	(11732)	1866 ac.	(2933 ac.)

**HAL, HAY and HAZ are air assisted TWIN sprayers

* Capacity includes water filling, road transport, boom folding etc.

Conditions: Forward speed between field and farm: 10 mph
Distance from field to water filling: 0.93 miles
Filling speed of water: 53 gal./min.
Water quantity: conventional sprayers 20 GPA, TWIN 10 GPA
“helping time” in the field (nozzle cleaning etc.: 60 sec/ha)

When multiplying number of hours in a season where spraying is possible and relevant **(Note 2)** with the capacity (ac./h) of the different sprayers, the number of acres that can be sprayed in a season is found. Maximum farm sizes for the different sprayers are found by dividing the total area which can be sprayed in a season with the average number of sprayings per acre per season. The farm sizes in **Table 2** are based on a Northern European example and a traditional number of applications **(Note 1)**.

In **Figure 1** the theoretical capacity for the 5 sprayers in acres per season is shown as a graph.

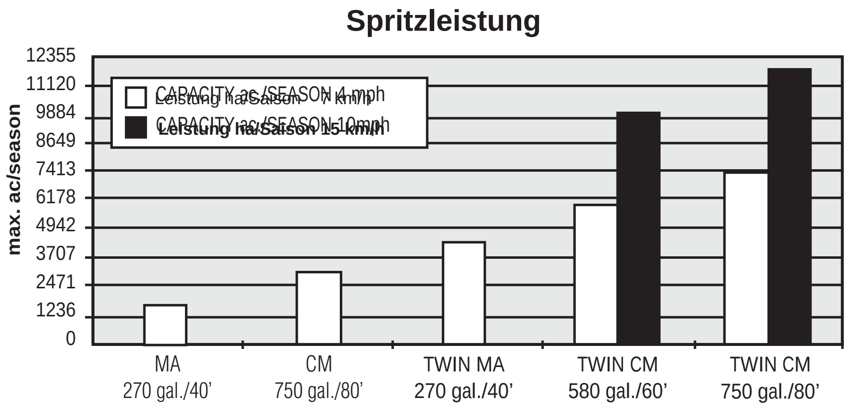


Fig. 1 *Theoretical capacity ac./season. The figure reflects partly that spraying with TWIN is seldom limited by the wind and furthermore the increased work rate due to lower water quantity with TWIN.*
The effect of higher driving speed is shown in separate columns.

1.3. More spraying hours available per day

Spray drift from a conventional sprayer can be so great that operators are advised to stop when wind velocities are higher than 7-9 mph. The Twin reduces drift greatly, and that volume now lost at the higher wind velocities of 18-20 mph, is less than that from the conventional working at it's safe wind speed limit **(Fig 2.)**. Under most conditions farmers get at least twice as many hours to perform an efficient spray job with the Twin compared to conventional spraying.

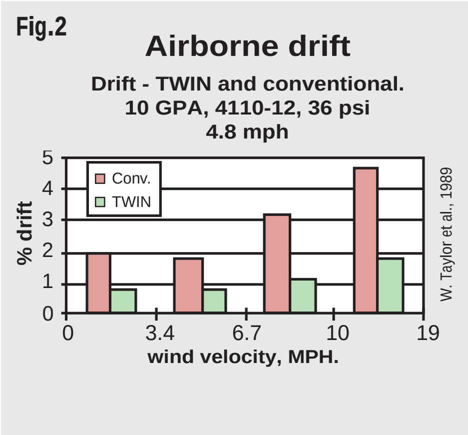


Fig. 2. *The importance of air assistance in controlling drift over a wide range of wind velocities is critical to the TWIN. Note that volume of airborne drift from TWIN air assisted sprayer in a high wind speed of 19 mph - is as low as the drift from the conventional sprayer at optimum spraying conditions (3.4 mph). The tests were carried out over bare ground/ short cut grass.*

1.4. Higher forward speed

Faster driving speed is also possible with the Twin. In normal conventional practice, fast spraying speeds produce more drift than the traditional range of 3 to 5 mph. The TWIN FORCE is constructed specially to utilize the efficient control of the droplets, provided by the air curtain principle, at spraying speeds which other designs find restrictive.

1.5. Reduced application rates

Excellent wind drift control makes it possible to reduce the volumes of water used to spray. With the TWIN lower water volumes can be compensated by spraying smaller droplets and in general the volume rate can be reduced to 50 % of conventional spraying.

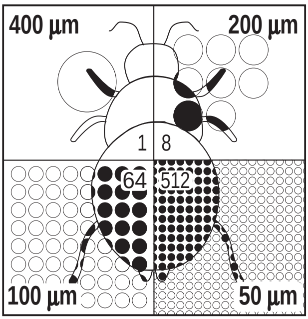


Fig. 3. *Each square represents equal water quantities but atomized into four different droplet sizes. The smaller the droplet size - the better the coverage. The volume rate can be reduced significantly - generally by 50 % of conventional use, sometimes more, because the small droplets are much more efficient for coverage - and with the TWIN air assistance they are safe to use.*

In the chapter “improved biological efficacy” the special advantages of spraying with a fine atomization are dealt with.

1.6. Less down time for tank filling

Extra driving and filling the tank is time consuming.
Lower water quantities to be used and less fillings, save time, energy and money. Spending 25 % of the total spraying time on the road is not uncommon for conventional sprayers - with TWIN the number of hours on the road can normally be reduced to half.

2. Reduced chemical dose rates / High quality products

Two demands both have to be met for successful spraying with reduced chemical doses:

- Spraying at the right time
- Use of a spraying technique which ensures a uniform distribution, high deposit and more complete coverage of target surfaces.

Increased biological effect of pesticides, can give many opportunities to use lower chemical doses. Exactly how much the individual user may wish to reduce the doses will depend on professional knowledge about crops, climate and pests as well as economic and political pressure.
An international user inquiry showed a reduction of 16 % on average in agrochemical use with the Twin, compared to the estimated use by conventional spraying.
The differences gained, however, ranged from 0 % to 50 %.
At one extreme some farmers only wish to spray at the most optimum time, and have no interest to reduce the chemical consumption. They grow very high value crops and demand the highest reliability of control.
At the other extreme, a 50 % reduction is regularly used by farmers, who have the knowledge and experience to reduce the dose to a threshold response they can accept - however this strategy does sometimes cost an extra spraying.

2.1. Improved biological efficacy

CONCLUSION
Biological testings are typically carried out under optimum conditions for conventional spraying. This is normal good field research and development practice and would be followed in the trials below.
The test areas are usually small and can be treated in a short period of time. Nonetheless, even spraying under optimal conditions for the best effect, further enhancement is still possible with the Twin.
In addition, spraying with Twin at a lower dose has been shown to be often as effective as conventional spraying with a full dose.

Spraying should ideally take place under favorable weather conditions with, for example, wind velocities under 6.7 mph, crops at medium height and all target surfaces fully exposed. Under those conditions a conventional sprayer can perform a very good job providing the field timing - in relation to the stage of the disease, pest or weed - can be achieved.
In reality such ideal spraying conditions are rare. The Twin sprayers show their force under one or more of the following conditions:

- windy
- crops/vegetation which are high and/or dense
- target surfaces for the spray are not exposed.

A review of more than 100 tests of weed control shows, that the degree of atomization of the spray which is applied, is a major factor in it's own right. The results are shown in **Table 3 and 4**.

Table 3. *The biological effect of decreasing droplet size when spraying with leaf herbicides.*

droplet size		% tests in which smaller droplets means			(number
µm (micron)	nozzle ex	higher effect	same effect	lower effect	of tests)
< 150	4110– 10	79	21	0	(24)
150-250	4110– 14	71	20	8	(49)
250-350	4110– 20	72	2	7	(46)
> 350	4110– 36	65	25	10	(40)
Total		71	22	7	(159)

M. Knoche, 1994

In approx. 70 % of the 159 tests, a decrease of the droplet size resulted in a better weed control.

Table 4. *The effect of decreasing droplet size with systemic and contact leaf applied herbicides.*

Mode of action of Herbicide	Results of decreasing droplet size (% of tests) higher effect	same effect	lower effect	(number of tests)
Contact	58	19	23	(26)
Systemic	76	24	0	(38)
Total	69	22	9	(64)

M. Knoche, 1994

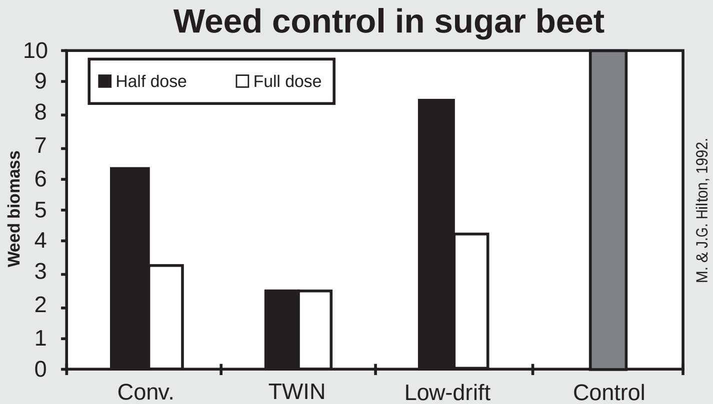
Contrary to common belief, better results with systemic herbicide use **(Table 4)**, are also achieved by decreasing the droplet size and the resulting better leaf coverage. Contact herbicides gave a better result in 58 % of the tests by decreasing the droplet size, but surprisingly, poorer result in 23 % of the tests were also possible.

In the following examples, results show that TWIN applications can lead to better biological performance than that of a conventional sprayer.
In these carefully conducted trials, only one variable was introduced, the use of Twin air assistance- all other factors being constant.
The TWIN use has, conclusively, led to a higher deposit and better distribution of spray liquid already described and this then prompts enhanced biological effects.

WEED CONTROL - examples

Figure 4 and 5 show the higher biological effect of weed control from spraying with Twin compared to conventional. Spraying Twin at half the normal dose is as effective as conventional spraying at full dose. Coarser sprays from low drift nozzles are worse than a conventional Fine spray application.

Fig.4



Speed: 5 mph
Nozzle 4110-12: 42 psi
Lowdrift nozzle: 51 psi

Water quantity: 10 GPA
Full dose: 1,05 goltix kg/ha + 0,285 kg/ha Betanal

Fig. 4. *The weed biomass was evaluated on a scale from 0 - 10, where 0 means 100 % kill and 10 is no effect. For conventional and Low-drift nozzle full dose was more efficient than $^1/_2$ dose - TWIN maintained the good control also with $^1/_2$-chemical dose rate.*

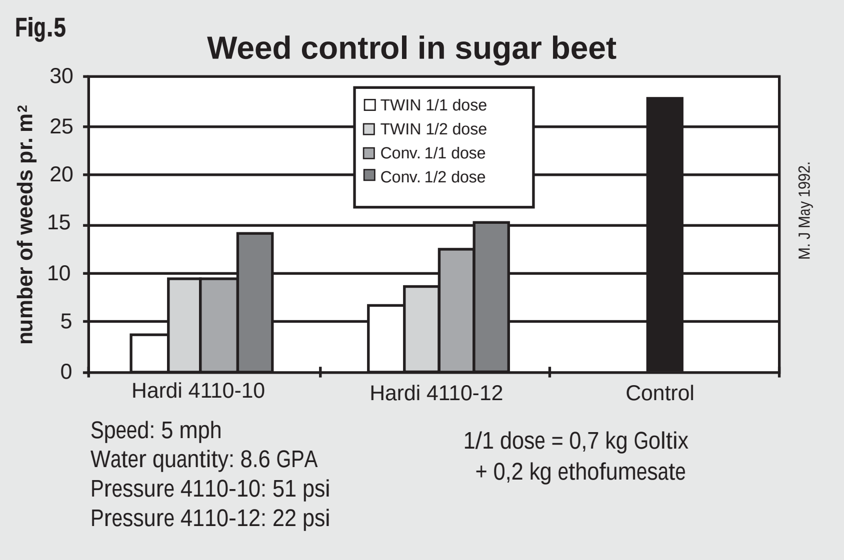


Fig. 5. *Air assisted spraying at full dose gives the highest weed kill. TWIN at half dose rate is as efficient as conventional spraying at full dose.*

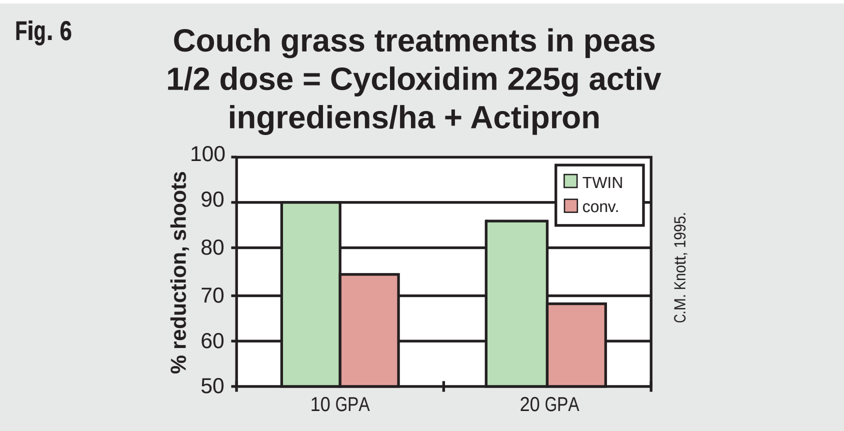


Fig. 6. *Control of couch grass - a perennial rhizotamous grass weed. Air assisted spraying gave a considerably better control of this serious grass weed than conventional applications at both 10 and 20 GPA. The results are at the recommended dose and show a tendency of higher biological activity at the lowest water quantity.*

Test of weed control in spring barley showed that a full dose of sulfonylurea - at 20 GPA sprayed conventionally - is, as expected, effective for the control of chickweed and fathen. Part of the effect is lost by reducing the dose to $^1/_3$ at respectively 10 and 20 GPA.
Only with Twin is the full effect still achieved at $^1/_3$ of the dose even with a reduced water volume of 10 GPA **(Fig. 7 and 8)**.

Fig.7.

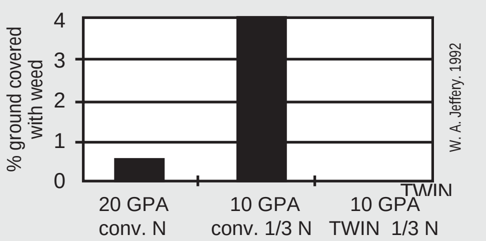


Fig. 7. *shows that 10 GPA and $^1/_3$ of the normal dose rate of sulfonylurea applied with the help of air assistance gives full effect.*

Fig.8.

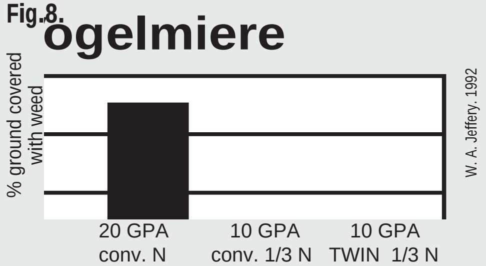
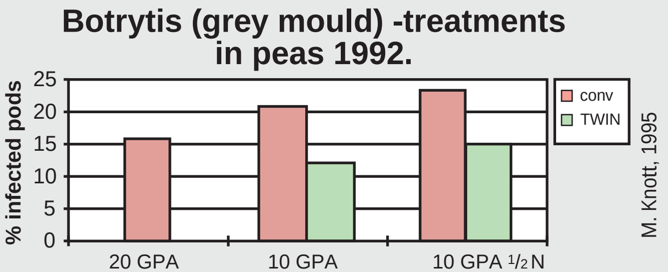


Fig. 8. *shows that $^1/_3$ of a full dose rate of sulfonylurea applied in 10 GPA of water is as efficient as 20 GPA and a full dose sprayed with a conventional sprayer.*

DISEASE CONTROL - examples

Fig. 9. *In a test on grey mould control in peas, the best results were achieved by Twin air assistance. Spraying $^1/_2$ recommended dose and 10 GPA were just as effective as spraying in conventional manner at 20 GPA.*

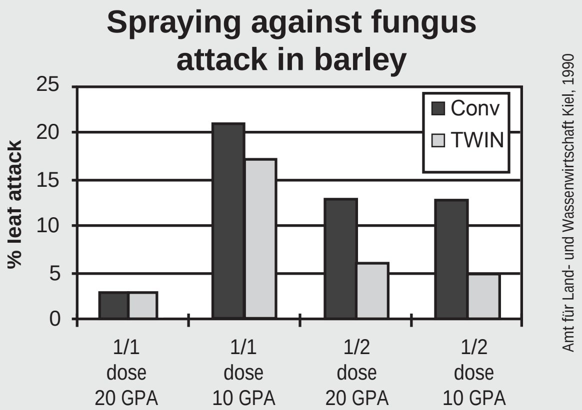
Fig.9.



Untreated: 39% infected pods. N = full dose of vinclozin 0.445 lbs a.i./acre

Results of two sprayings to control fungus diseases in winter barley were measured as % attack on leaves. The biological control was highest at full dose and 20 GPA with both spraying techniques. However, with all the other treatments Twin spraying resulted in the least fungus attacks compared to conventional spraying **(Fig. 10)**. A similar test was carried out two years later, but here the effect was measured as crop yields instead of % leaf attack **(Fig. 11)**.

Fig.10.



Speed: 3.7 mph
Wind velocity: 2.2 - 4.5 mph
10 GPA: nozzle: 4110-12 and pressure: 17 psi (normal recommended pressure min 22 psi)
20 GPA: nozzle: 4110-18 and pressure: 25 psi

N = Sportak 0.15 GPA (ES 32) and Folicur 0.10 GPA (ES 49)

Fig. 10. *A clear trend that the air assistance is helping keep a good efficacy when the dose rate is reduced.*

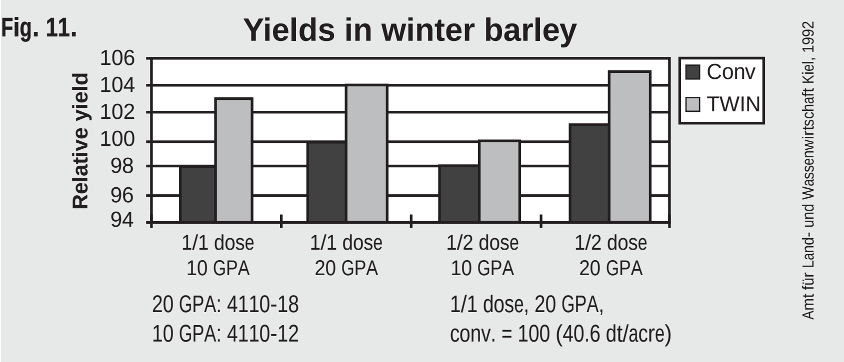


Fig. 11. *Crop yields were highest from larger water volume rate use. In addition, there is a clear trend for Twin spraying to provide the highest yields.*

PEST CONTROL - examples

In some conditions, a low infestation of a pest can be controlled adequately with conventional techniques. However, when the insecticide is under intense pressure to control large numbers of pests that can be concealed on the under side of potato leaves as well as the top, then Twin use shows real benefits again **(Fig. 12)**. The more rapid knock down effect that is so critical when avoiding aphid transmitted virus diseases is attributed to the more uniform coverage of deposit from the Twin.

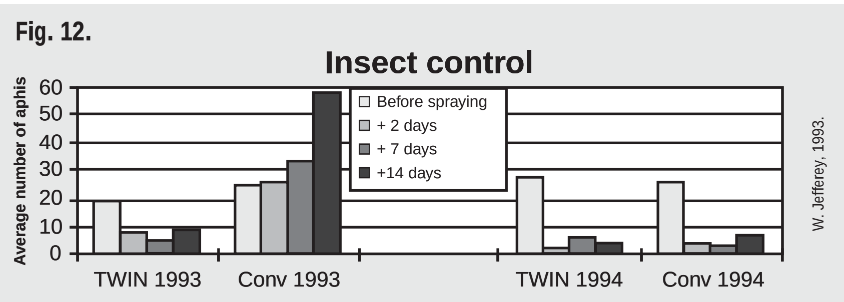
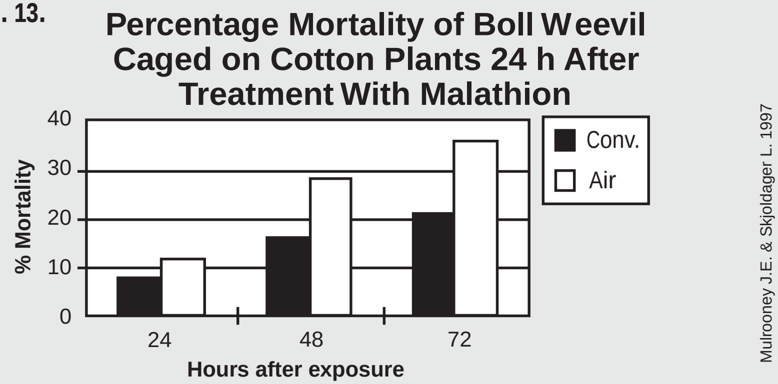


Fig. 12. *Aphid spraying in potatoes over two years show the dramatic differences from year to year. In 1994 both TWIN and conventional spraying gave very good aphid control. But the year before only the conditions for the aphids were obviously better and only the TWIN gave sufficient control.*

The results of spraying insecticide in cotton show, that air-assistance can significantly enhance the efficacy of insecticides for control of two cotton pests that are difficult to control with conventional application methods **(Fig. 13 and 14)**.

Fig. 13.

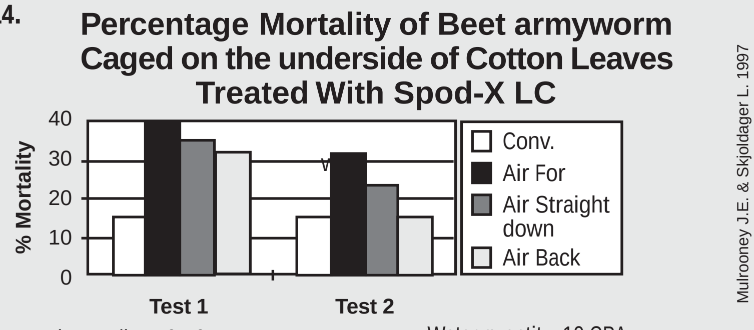


Nozzle : Hardi 4110-08
Pressure: 45 psi
Speed: 5 mph

Water quantity: 5 GPA
Matlathion: 1 lb./acre

Fig. 13. *Mortality of Boll Weevil*

Fig. 14.



Nozzle: Hardi 4110-10
Pressure: 50.8 psi
Speed: 4 mph

Water quantity: 10 GPA
Spod-XLC: 100 ml/acre

Fig. 14. *Mortality of Beet armyworm*

DESICCATION - example

Desiccation of many crops prior to harvest such as linseed typically demand high water volumes to ensure adequate leaf/stem coverage of the contact acting product within all points of the canopy. Twin gave both the quickest and most effective desiccation regardless of water volume rate used. Although conventional lower water volumes can be shown to be as effective as the highest volumes, such commercial use is restricted for fears of drift over adjacent crops and often poor stem contact.

Fig.15.

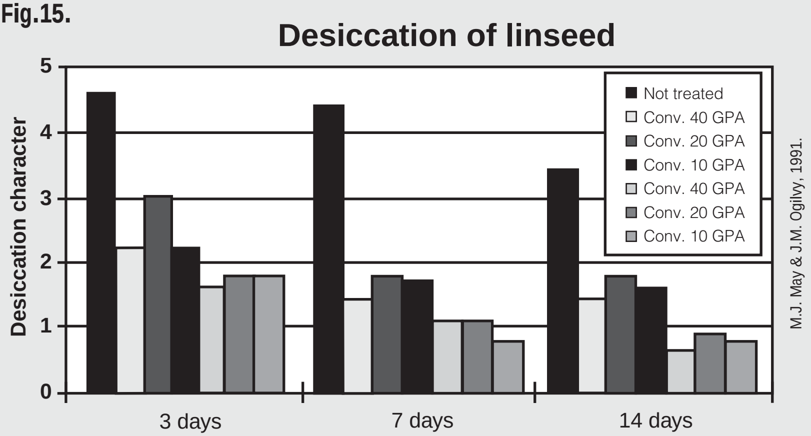


Fig. 15. *Desiccation of linseed.*

2.2. Even liquid distribution

CONCLUSION

Twin gives a more uniform distribution of the spray liquid over the treatment area under the boom. In addition, weed that are concealed such as those on the lee side of “ridges” or clods will no longer be missed. Hence, one more important qualification for successful spraying at reduced chemical dose rate is well justified.

Many different nozzles have been tested over the years with the Twin System. So far, the 110° flat fan nozzle shows an unsurpassed uniformity of spray distribution at all working boom heights and throughout the wide pressure range of 20 psi to 75 psi.

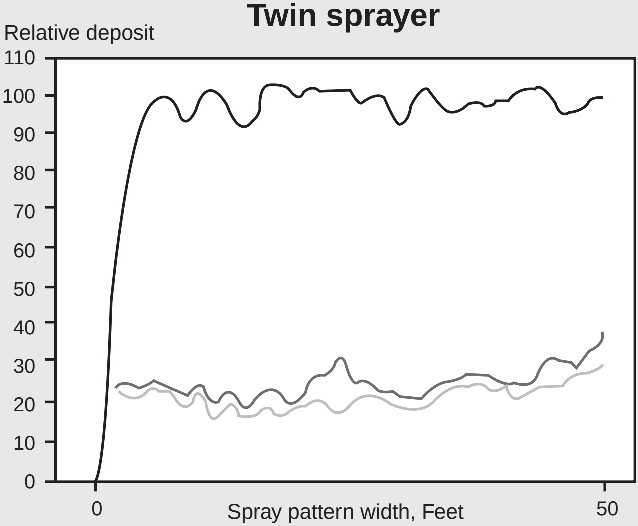
TWIN air assistance ensures a uniform distribution over the canopies, even under windy conditions **(Fig. 16)**.

Fig.16.

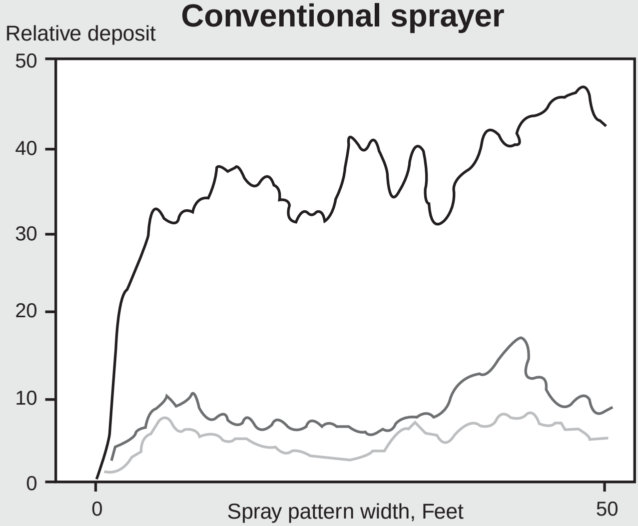
Distribution in wheat - Twin and conventional

The three curves represent three levels in the crop (top, middle and bottom).
Water quantity: 20 GPA

Twin sprayer



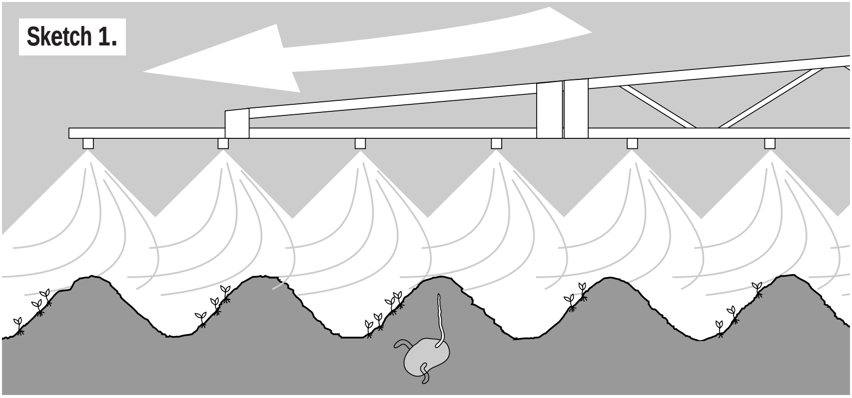
Conventional sprayer



V. Hofman, 1991.

Weed control in potatoes

Wind from the side of the direction of driving normally results in a poor deposit on the lee side of the potato "<u>ridges</u>" **(Sketch 1)**.
Conventional sprayers have to spray in calm weather to avoid these "shadow" areas of inadequate herbicide deposits.



Sketch 1. *The "Ridge effect", which allows weeds on the lee side to be not contacted by the herbicide, when spraying conventionally under windy condition.*

Potato growers using Twin sprayers have reported, that the "ridge effect" is not a problem when using air assistance. Droplets maintain their direction and not being affected by the wind, make contact with weeds irrespective of their position on ridges. The result is a better effect of the herbicide treatments without the troublesome stripes of weeds along the ridges.

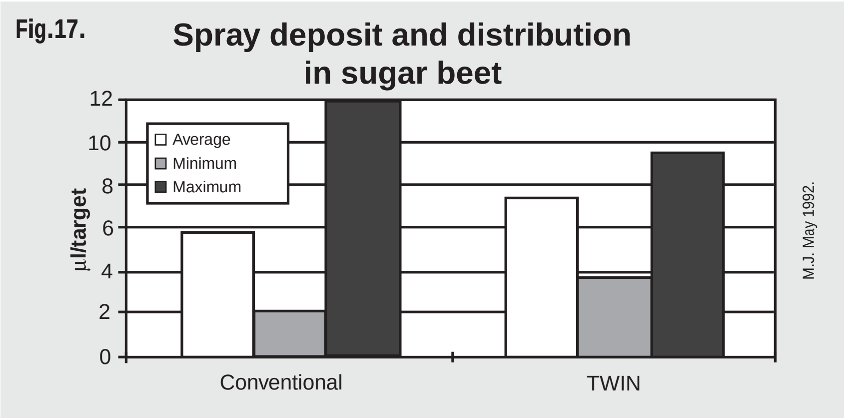


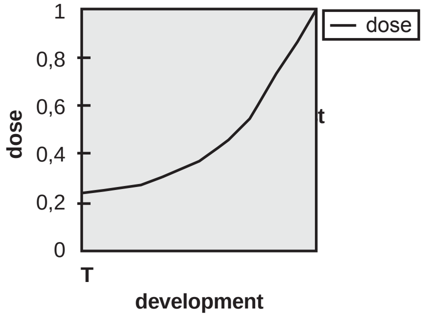
Fig. 17. *At Morley Research Center in Britain, independent measure-ments of spray deposits in sugar beets have been made*.

The total deposit of spray liquid on the simulated grass weeds was 20 % higher with Twin compared to conventional because there is less drift and less deposit on the ground. But more important, the difference between the highest and lowest deposit was significantly reduced when spraying with Twin compared to conventional - there was less variability. The minimum deposit values are also critical in these studies for they are indicative of the potential for reducing chemical dose rates.
The more even distribution performed by TWIN is a result of less wind sensitivity, in particular, when using finer sprays on smaller target plant surfaces. Higher deposit and less variation are important criteria for successful plant protection.

2.3. Optimum timing

Field work rates, dose and effect
The most important factor concerning spraying is weather condition. Can you spray now when all other conditions dictate that you should? Here the higher work rates with Twin offer a great advantage, and as an equally positive side effect, this better field timing makes it possible to achieve the highest efficacy of the plant protection product, spraying at the most optimum time (especially with reduced dose rates).

Theoretical relation between timing and dose rate



Principle sketch
For example, when spraying herbicides in beet or potatoes it is generally accepted that approx. 2 days are available to spray the area when the weed is at the dicot stage and the lowest possible dose can be safely used.

This independence of the wind, which frees you to spray at the most optimum time - and thereby achieve the best result with the lowest input - when coupled by the Twin to the further positive benefits of greater, more uniform spray deposits- are the keys to enhanced reliability and biological effect.

APPENDIX A

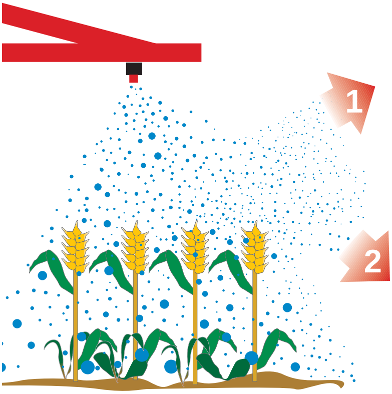
Efficient drift control

CONCLUSION
Efficient wind drift control, thanks to the unique combination of air assistance and co-angling of air and liquid, gives TWIN the dual opportunities of high field work rates and minimal consumption of pesticides.
The most difficult spraying condition for reducing drift is - with all spraying techniques - over bare soil or a low crop and the wind coming sideways. Therefore most wind drift testing is carried out under these “ worse-fit” conditions. In spite of this restriction, it is possible with TWIN to reduce the drift by 50 % or even more when spraying at early growth stages **(Fig. 2)**. Spraying at late growth stage, the Twin is able to nearly eliminate the problems associated with wind drift.
Freedom from restrictive winds, automatically permits the TWIN to gain higher field work rates, that is acres that can be sprayed per day. At the same time these enormous benefits can be gained with a higher degree of target coverage that finer atomization allows.

Both wind drift and spraying capacity are factors of high significance to operators. Indeed, these two restraints are often interdependent because wind drift may be the limiting factor to optimizing work rates.

There are two main components to the consequence of wind drift, <u>airborne drift</u> and <u>sedimentation drift (fall out)</u> **(Sketch 2)**. The airborne drift is responsible for air pollution and may damage susceptible plants in fields situated far from the treated area.
The sedimentation drift is due to droplets, which typically fall to the ground in a distance of 3 to 65 ft. from the downwind edge of the boom.
This effect can be a potential risk to neigboring crop and as a pollutant of open water such as streams. It is documented that both kinds of drift can be significantly reduced by the use of the Twin principle **(Fig. 18 and 19)**.

Sketch 2.



1. Airborne drift
2. Sedimentation drift

Fig. 18

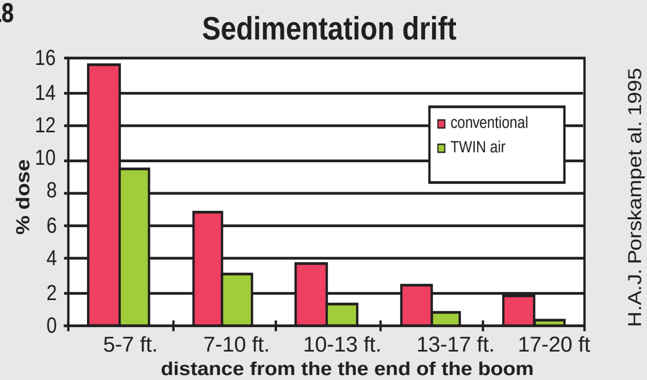


Fig. 18. *"Dosing" on the downwind out of the treated area. TWIN has halved the deposit out of the target area, compared to spraying with a conventional sprayer. Both systems applied 16 GPA of Fine Sprays (4110-12, 44 psi).*

It is of great interest to note that air assisted sprayers in the Netherlands are sold with subsidies because of this reduction in downwind sedimentation of pesticides. Such grants are the consequence of a government supported aim to encourage farmers to buy more environmentally friendly spraying equipment. Furthermore, based on the same results, Dutch farmers may reduce the “no-spraying zone alongside ditch edges” using the Twin - an opportunity not allowed to users of a conventional sprayer.

Recent experiments carried out by the Danish Institute of Weed and Soil Sciences showed significant reduction of both airborne drift and sedimentation drift **(Fig 19a and 19b)**.

In **Figure 19a** it is seen that the use of TWIN air assistance to the small 4110-10 nozzle reduced the drift remarkably compared to the same nozzle without air and even compared to the larger 4110-14 nozzle. The Kyndestofte Air sprayer has not been able to reduce the drift - in fact the drift level is higher than when no air assistance is used. With the Danfoil (pneumatic nozzle / shear nozzle) the drift is at the same low level as with the TWIN, and this is a considerably better result than previously achieved with the Danfoil. The result should be regarded on the basis that the manufacturer has altered the recommendations of air adjustment. The new recommendation implies that the atomization is coarser and thus less sensitive to wind. But at the same time it is an adjustment where the effect on weed control is not examined.

Reduction of wind drift when spraying over bare soil

There are several air assisted sprayer systems likely to be able to reduce wind drift when treating a crop with an obvious leaf canopy. In this situation, which is always the easiest in which to control drift, the air within the vegetation is displaced by the fan driven air. The capture efficiency of the drops will always be greater than that gained from spraying at earlier growth stages in the absence of much plant cover.

Obviously, many applications take place before the crop covers the ground, and it is under these common spraying conditions that only One air assisted sprayer is able to document a real reduction in both airborne drift and sedimentation drift. It is well proven, even when applying Fine and Very Fine sprays to bare ground - the ultimate drift reducing challenge - the Twin gives a 50 % reduction in airborne drift **(Fig. 2,18,19)**. This advantage increases to more than 90 % reduction when spraying over a developed crop.

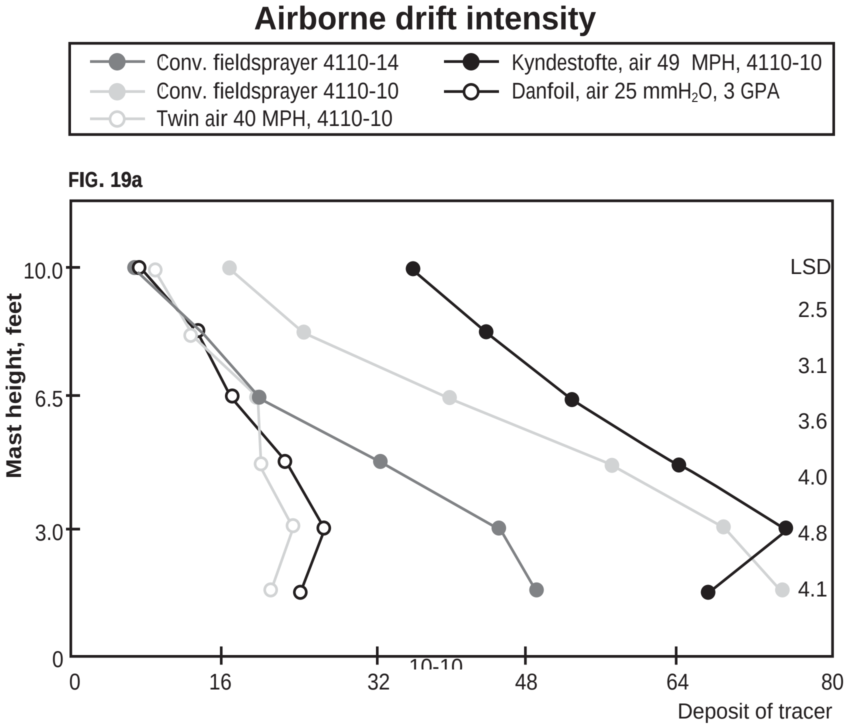


FIG. 19a

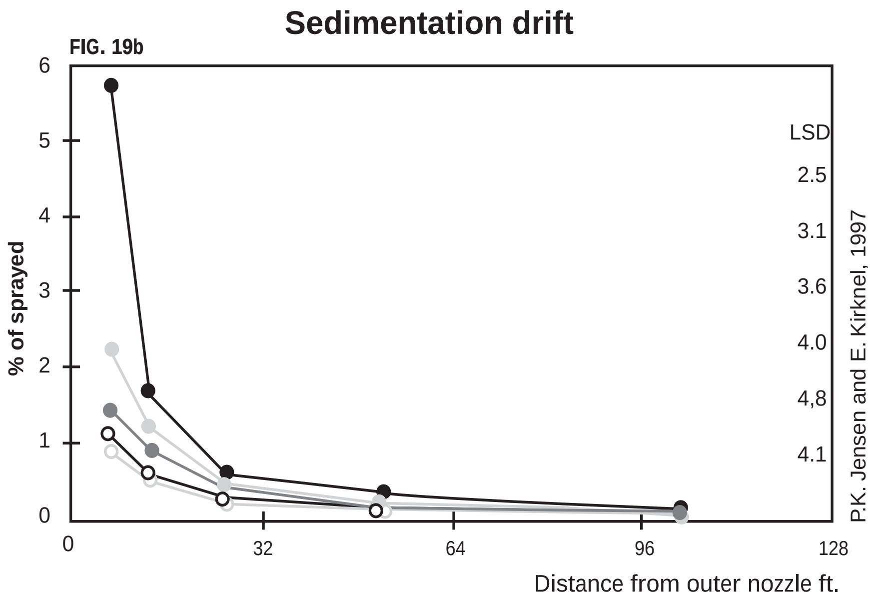


FIG. 19b

Fig. 19a and 19b. *Drift from field sprayers in recommended adjust-ments measured in different heights on masts in 16 feet´s distance from the sprayed area* **(*Fig. 19a*)** *and on vertical objects placed in increasing distance from the sprayed area* **(*Fig. 19b*)**.

Table 5. *Reduction of airborne drift from the TWIN sprayer compared to a conventional sprayer. Sprayed with a very fine spray quality (i.e. 4110-10 nozzle). It is more difficult to reduce wind drift in a crop with large rigid leaves than some flexible crops like cereal, but even so, in sprouts and lettuce a considerable drift reduction can be achieved.*

	Growth stage: early (bare soil / low crop)	Growth stage: late
In general	50-70% reduction	
Cereal		90-98 % reduction
Beans		84 %
Peas		83 %
Brussels sprouts		76 %
Lettuce		68 %

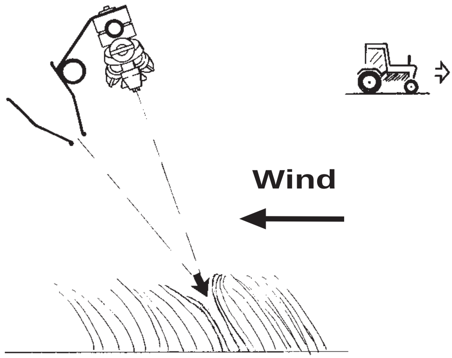
Hardi International 1988-93

Compensating for wind direction

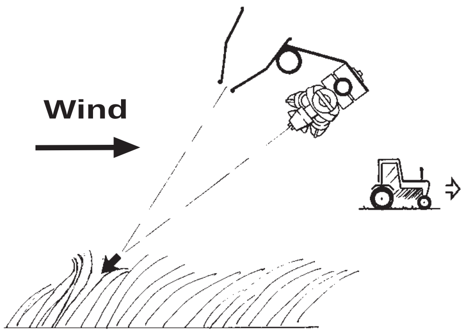
TWIN is the only air assisted sprayer that makes it possible to angle the “air-curtain” together with the spray swath of drops, thereby making it possible to compensate for the *direction* of the wind:

Angling of air and nozzles gives full advantage of the air assistance:

Is the direction of wind against the driving direction, you angle forward.



If the wind is coming in from your back, you angle the air curtain to the rear.



Co-angling of air and nozzles - Unique TWIN feature

To transfer as much energy as possibly to the droplets, the directed air entrains the spray about 12 inch. below the boom - where the 110° flat fan nozzles have already achieved sufficient overlapping - a unique system that results in a very uniform distribution of the applied liquid under the boom. This synchronised system of angling of air and liquid is constructed specifically to maintain this critical interaction of air and spray even when the boom is angled. Therefore the nozzles and air outlet are fixed in this optimum position, being angled in one easy operation.

APPENDIX B
Increased on-target deposit and more uniform coverage

CONCLUSION
It is proven that Twin provides a higher spray deposit on both horizontal and vertical surfaces of the crop or weed with more uniform coverage of the whole plant from top to bottom. These opportunities provide yet further means to reduce the amount of agrochemical and their field reliability.

The Twin system gives you the opportunity to exploit all the benefits of fine atomization without the disadvantages that normally restrict use.
A fine atomization can result in higher deposit and more complete coverage of plant surfaces.
However, the use of a conventional sprayer applying such fine drops, results in unacceptable wind drift and uneven distribution under the boom as well as a lower penetration of the plant canopy.

The Twin system, with the precise positioning of air and flat fan nozzles, has no such wind dependency and offers an optimum distribution of spray liquid. The drop-laden air curtain also increases the penetration in the canopy considerably. Tests of distribution in several crops and high speed filming show, that the air stream opens the canopy to give a better penetration and lower deposit on ground compared to that seen with conventional spraying. This reduced ground deposit is a result of a change of direction of the air stream just above the ground, the drops now following soil surface contours to nearby plants instead of impacting on the ground.

The high speed filming also gave a clear picture of how the more uniform deposit on the upper- and under surfaces on the leaves is achieved; it is the combination of rapid changing air directions in the canopy and leaf twisting within its dense spray cloud that ensures all surfaces are fully coated. By variation of the airspeed and angling, it is possible to direct more of the spray liquid from being deposited on the top of the canopy, to further down at the bottom. In this way a more uniform distribution of pesticides on all parts of the plants can be achieved.

The ability to relocate and control the distribution of fine sprays - as and when needed - in most cases makes it possible to reduce water volume rate by 50 % with Twin compared to conventional.

When looking at plant deposit in cereal **(Fig. 20)** it shows that air assistance increases plant deposit dramatically and at the same time the loss on the ground can be reduced. Also it has been proven that when the wind speed and wind direction allow, the co-angling of air and spray offer special advantages manipulating the deposit to certain areas in the canopy, for instance the deposit on the ear can be increased when angling forward **(Fig. 20)**.

Fig. 20

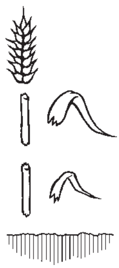
	Angle rearward		Angle forward
Ear	- 1 %		+ 46 %
Top leaf	+ 43 %		+ 61 %
Top stem	+ 11 %		+ 31 %
Lower leaf and stem	+ 101 %		+ 14 %
Ground	- 41 %		- 66 %

Fig. 20. *Change (%) in deposit from 13 GPA application when spraying with Twin Stream compared to conventional. With the boom angled rearward Twin gave i.e. 43% higher deposit on the top leaves compared to conventional.*

If the target area is restricted to a certain part of the plants it is always a good idea to test different air/angle settings with water sensitive paper placed on the spray target (angled similar to target) to find the most efficient setting before spraying.

Testing carried out in a laboratory support the findings from **Figure 20**, see **Figure 21**.

Fig. 21.

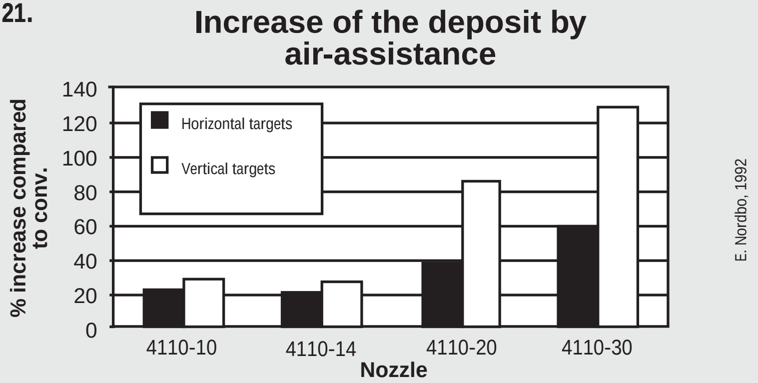


Fig. 21. *Testing in a laboratory shows that the magnitude of deposit increases on artificial and horizontal targets when air assistance is applied. The horizontal targets are simulating broadleaf weeds or crops, the vertical grass weeds or stems or ears on plants. For all relevant nozzle sizes at least 20 % increase in deposit has been observed.*

A test with tracer in sunflowers has shown that for all tested volume rates a more uniform and higher deposit on lower parts of the stem was achieved **(Fig. 22)**. The purpose of the test was to simulate a spraying against Sclerotinia.

Fig. 22.

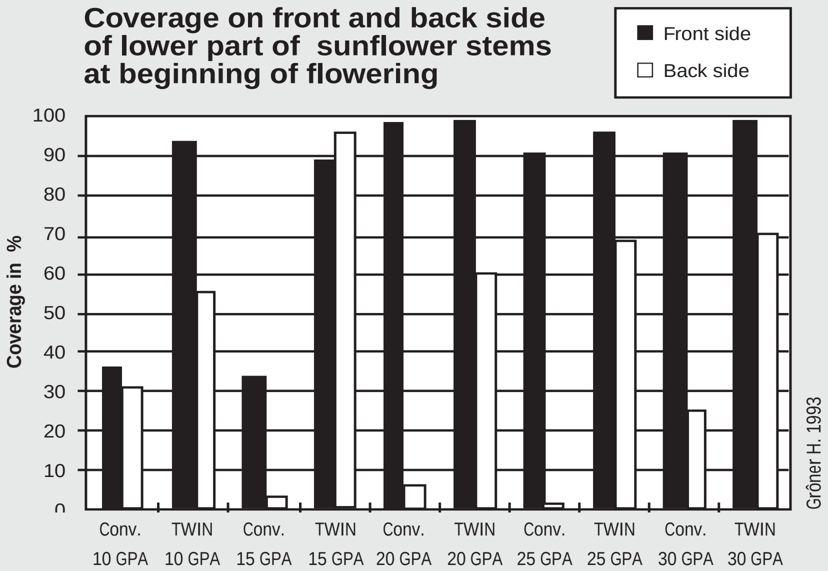


Fig. 22. *10, 15, 20, 25 and 30 GPA all applied with and without air assistance in a sunflower crop.*

Special demands, such as some soil acting insecticides, may require a high deposit on the ground under a pronounced leaf canopy. Larger water volumes and bigger droplet sizes with full air assistance have been shown to be particularly effective in reaching these areas - an opportunity not available to conventional spraying practice **(Fig. 23)**. These tests were made in Britain with the co-operation of WH Knights Ltd, one of Europe's largest vegetable growers and HARDI INTERNATIONAL. After WH Knights Ltd had sprayed with Twin air assistance for a year, the company has bought 4 extra Twin sprayers from Anglia Sprayers Ltd for all their plant protection needs in cabbage, parsnip, carrot and other vegetables.

Fig. 23.

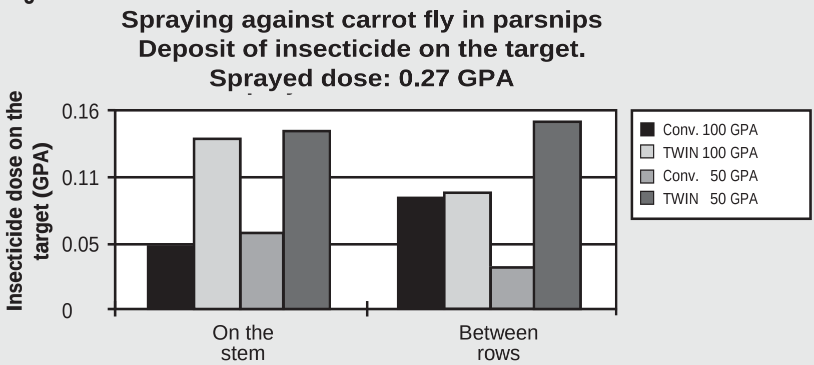
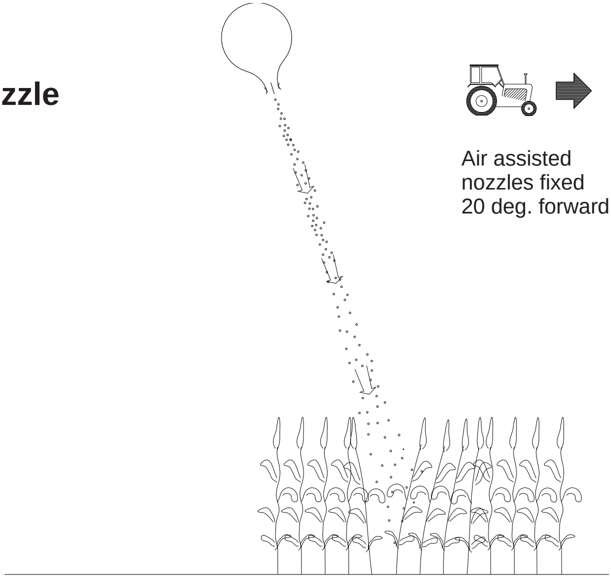


Fig. 23. *Spray deposit tests in parsnips show how much of the sprayed dose (0.27 GPA) of the insecticide - Hostathion - was deposited on those target sites where it is most active against carrot fly using. Four different spraying techniques were used. The standard manner of spraying parsnips with a conventional sprayer is 100 GPA, but Twin air assistance doubled the deposit on the target. The deposit was higher when spraying 50 GPA with air assistance instead of spraying 100 GPA without air assistance.*

APPENDIX C

Air assisted nozzle



Principle

A pneumatic sprayer: drop formation is dependent on air assistance.
The higher the air speed / volume the smaller the droplets. Spray quality at medium to high air speed corresponds to the medium to smallest sizes of flat fans.

Penetration/ Drift control/ Coverage

Works well in well developed crops.
On bare ground/low vegetation the user is locked to using very little air and thus very coarse atomization resulting in poor coverage, especially at the very low volume rates possible (3-6 GPA) with this type of sprayer - or accept a higher level of drift/poorer distribution.
It is not possible to angle the boom and counteract for wind direction.

Documentation

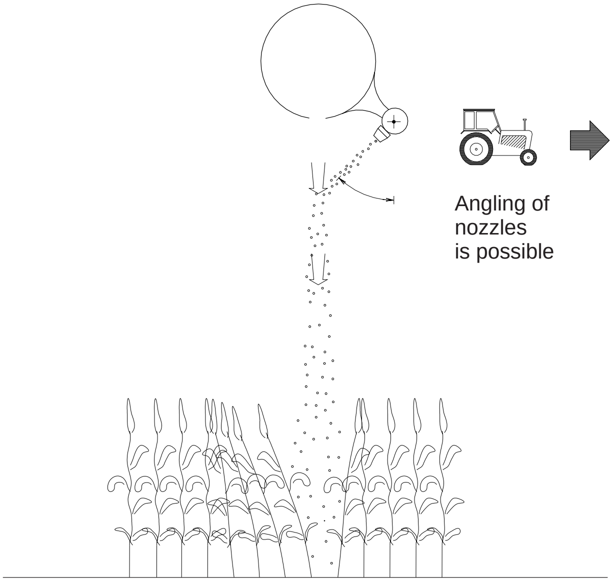
A limited number of independent test results. No documentation of the biological effect of “low air - large drop” setting of the sprayer which is used for minimizing drift.

Maximum air volume is relatively low compared to air assisted sprayers.
813 CFM/ft.

Comments

Conventional spraying (liquid fertilizers) is not possible.

Sleeve boom



Principle

A perforated air bag along the boom distributes the air vertically down through ø 1.6 inch. air jets spaced 1.6 inch. About 3.9 inch. from the air outlets the air meets the droplets from cone nozzles placed on the spray boom with 3.9 inch. spacing. The liquid distribution from cone nozzles is sensitive to nozzle pressure and only optimum for a very limited pressure range.

Penetration/ Drift control/ Coverage

Works well in well developed crops.
Limited possibilities for targeting deposit and minimizing drift over low vegetation because the air cannot be angled together with the nozzles.
When using low volume rates the user is locked down to use a very fine atomization because there are twice as many nozzles on the boom compared to a normal sprayer.

Documentation

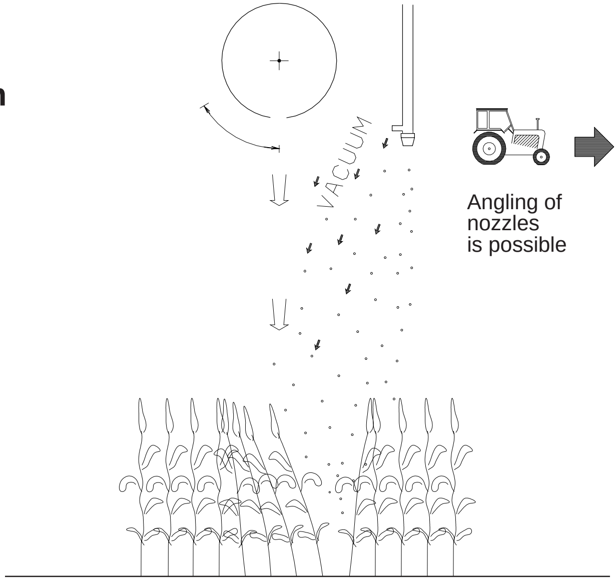
A limited number of independent test results

A sprayer type originally developed for cotton spraying, thus a necessary potential of 4840-5420 CFM/ft., depending on boom width.

Comments

The design does not allow using 20 inch. nozzle spacing, because this would lead to over or under spraying where the swaths meet. High power consumption.

Vacuum system



Principle

An indirect use of air assistance. Sleeve boom type air bag (see this).
In stead of using the air as means for transporting the droplets the air is used to create a vacuum behind the nozzles. The nozzles are fixed to spray vertically down. It is possible to angle the air outlet vertically down or backwards; but angling forwards to counteract for a head wind or high driving speed is not possible.

Penetration/ Drift control/ Coverage

When there is a crop to catch air and liquid this sprayer type probably has a potential for good penetration and to reduce drift. On bare ground or low vegetation test results indicate that the maschine could increase drift .

Documentation

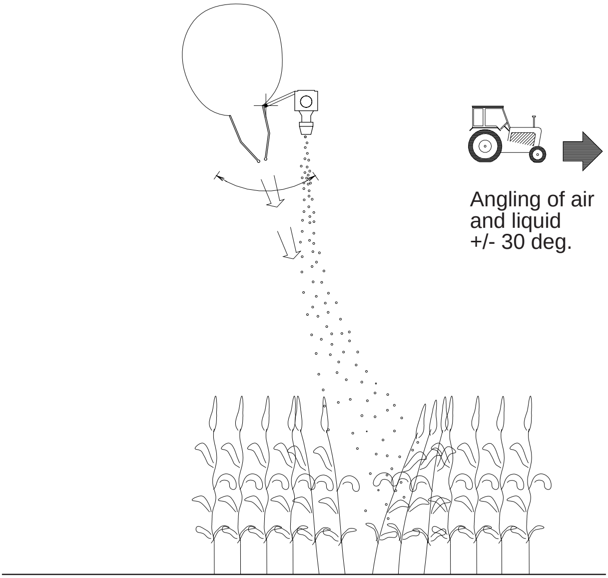
Danish and Swedish documentation of drift increase/no effect on drift. No biological results available.

Max 3872 CFM/ft., depending on boom width

Comments

The vacuum system is a kit to be mounted on conventional booms - an addition of 165-209 lb. on the conventional suspension, which has been constructed for less weight, can cause some problems with boom stability.

TWIN SYSTEM



Principle

The only air assisted sprayer with the patented possiblity to angle air and liquid together in such a way that it is possible to counteract for wind direction and forward speed, with out compromizing on the even liquid distribution.
Drop sizes can be chosen independently of air speed and volume.

Penetration/ Drift control/ Coverage

Drift tests have beeen carried out under a wide range of different conditions and over different crops proving a very high drift reduction efficacy.
Penetration studies in dense crops like potatoes show increased deposits deep in the crop as well as back side of leaves.

Documentation

Penetration, deposition studies and biological efficacy tests from many countries and in a wide range of different crops have proven the efficiency of the system.

2904 CFM/ft. for STREAM SYSTEM and 3872 CFM/ft. for FORCE

Comments

Due to the very efficient drift crontrol over both bare ground, low and developed crops, a TWIN sprayer has a very high capacity.

NOTE 1

Input for the results presented in Table 1 page 4.

Farm type

Crop	% area	chemical costs	number of treatments
Wheat	50%	32 US$/acre	4
Malt barley	20%	18 US$/acre	3
Sugar beet	20%	112 US$/acre	5
Peas	10%	30 US$/acre	4
Average		45 US$/acre	4

Borrowing interest rate 9%, annual write off 10% p.a., wages 16 US$/hour, tractor costs 22 US$/hour.

	Average number of hours available for spraying	**Volume rate**	**Speed**
Conventional	3 hours/day	19.3 GPA	4.3 mph
TWIN	6 hours/day	9.6 GPA	4.3 mph

Predicted demands for spraying equipment:

185 acres	40 ft. hydraulically boom
370 acres	60 ft. hydraulically boom EC (electrical) operating unit
740 acres	80 ft. hydraulically boom EC operating unit, trailed sprayer

NOTE 2

Input for table 2 page 6.

How many hours are available for spraying during a season ?
It is ideal to use the observations from the nearest climatic stations e.g. from the last 5 years. In table 6 is shown the country average for 10 Danish localities for 1989 - 1991. Only the most busy spray months are included.

Wind speed	April	May	June	Total
max. 10 mph	34	138	198	371
max. 18 mph	114	298	349	761

Danish Institute of Agriculcural Science

Table 6. *Average number of spraying hours* available*
Source: Statens Planteavlsforsøg, Afd. for Jordbrugsmeteorologi.
*Conditions: Minimum 3 consecutive hours/day under following conditions: temperature above 34°F increasing to min. 50°F during daytime. No frost the following night, less than 0.1 mm rain/hour and less than 2 mm rain from 3 hours before application and 6 hours after application, relative air humidity between 50 and 95 %.

Application to take place between 4 a.m. and 8 p.m.

In practice you cannot utilise all the periods with favourable weather conditions for spraying. The fields may have been treated recently or it is not necessary to spray at a certain time. It may be somewhat problematic to establish how many of the possible spray hours it is also relevant to spray. Just like the number of good spray hours will vary from year to year, spraying need will also differ. Furthermore, the need of spraying in various crops may also coincide and this will further increase the demands to spraying capacity.

How many spray hours are at disposal if all sprayings must be carried out in time?
In the following it is estimated that in April and May it will be relevant to spray during approx. $^1/_2$ of the hours where it is possible.
In June it will only be relevant to spray $^1/_3$ of the time.
Under these conditions you can see from **Table 7** that with a conventional sprayer, where spraying should stop at wind velocities above 10 mph, 136 hours are at disposal against 293 hours with the TWIN, where you can spray at wind velocities up to 18 mph.

Table. 7. *Number of hours at disposal for treatment where spraying is relevant (April, May, June). If you divide the relevant number of hours with the actual capacity of a sprayer you can find out how many ha a certain sprayer can treat in one season.*

Wind speed	Hours
max. 10 mph (conventional sprayer)	136
max. 18 mph (TWIN sprayer)	293

Danish Institute of Agriculcural Science

As always when using average figures information about extreme situations is lost: It is also relevant to know how many hours are at disposal in the most difficult year. In this connection you may consider if it is worth having a certain over-capacity enabling you also to do the necessary applications at the best time in difficult years.

For the sake of completeness we can mention that there is another way to approach the capacity demand to the sprayer. This method demands that you know your crops and their infestation extremely well and furthermore know the relation between the effect of the pesticides and the treatment time. The principle sketch is shown at page 22. A well-know example is weed spraying in sugar beet where you can obtain full effect even with $^{1}/_{4}$ dose, if you can treat the whole area in max. the two days which are generally at disposal to catch the weed at the cotyledon stage.

For i.e. Danish conditions you can for the most ordinary crops roughly define following spray “windows”, i.e. the time at disposal in order to ensure a quality result with the lowest possible dosing:

Cereal	5 - 6 days
Sugar beet	2 days
Potatoes	1 day

Compared with the size of the area of the various crops the above gives a good hint of the necessary capacity. In this connection another consideration is to be taken: how often do you have to spray simultaneously in various crops at the optimum spraying time.

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Notes:

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