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Reducing Spray Drift

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1. Introduction

Spray drift can be defined as unwanted physical movement of spray droplets into non-target areas by air movements while application and after application (R. Frank, 1988). It can be divided into two main categories by type of occurrence.

1.1 Vapour drift

This kind of spray drift is occurring by non target movement of vaporize pesticide related to its evaporation and volatility characteristics . As it can be clearly seen, this kind of spray drift is much more depended to pesticide characteristics than used spraying techniques (Robert E. Wolf, 2000). Evaporation can happen during application or after application. But volatility caused drift can only happen after that pesticide dried on plant surface (R. Frank, 1988).

1.2 Particle drift

Spray droplets move on air from nozzle to target surface when they have pulverized. During this movement droplets are very open to environmental effects. Air movements and wind can cause to spray drift. This kind of spray drift is happening during application. (Robert E. Wolf, 2000).

2. Drift dynamics

Beside the wind, droplet size is another important factor which is increasing drift. There is an inverse proportion between droplet size and drift. Decreasing of droplet size will increase drift risk.

Generally micrometer is used for measurement of spray droplets. Studies showed droplets under 150 micrometer diameter cause a significant spray drift risk (Vern Hofman and Elton Solseng, 2001). Also droplets under 50 micrometer diameter vaporize before reaching to target surface (Ergin Dursun et al.,2005).

Decreasing of droplet size will also be decreased mass of droplet and because of these, droplets will travel on air longer time. Longer time of travel will increase risk of spray drift (R. Frank, 1976; Vern Hofman and Elton Solseng, 2001).

An equation to define the effect of evaporation on the change of the mass of the drop was described by (Pruppacher and Klett,1997) where:

$$\frac{dm}{dt} = \frac{4\pi r M_w D_{wa} f_w}{R} \left(\frac{p_{sat}(T_w)}{T_w} - \frac{f p_{sat}(T_a)}{T_a} \right)$$

m = mass of the drop (kg)
t = time(s)
r= radius (m)
M_w = molecular mass water (kg.mol⁻¹); value 18.015x10⁻³kg)
D_{wa}= diffusivity of water vapur in air (m²s⁻¹)
f_w= mean ventilation coefficient for water vapour. This coefficient gives the ratio between the water vapur mass flux for a moving drop and the water vapur mass flux for a non-moving drop.
R= gas constant (8.314510 J mol⁻¹K⁻¹)
p_{sat} = saturation pressure water (Nm-2)
T_w= temperature water drop (K)
f= relative humidity divide
Smaller droplets will be on air, longer than bigger droplets and this will make smaller droplets weaker to spray drift. Droplet size’s effect on travel time on the air is showed at Table 1.

Diameter(microns)	Time to fall in 3 meters
1 (fog)	28 hours
10 (fog)	17 minutes
100 (mist)	11 seconds
200 (fine spray)	4 seconds
400 (coarse spray)	2 seconds
1000 (coarse spray)	1 second

Table 1. Droplet size classification(Ross and Lembi, 1985)

Studies showed potential risk of spray drift is significantly decrease when the spray droplet is bigger than 150 and 200 micron.

Smaller droplets have bigger surface area when compared with bigger droplets. This is result of lossing mass. Less mass and bigger surface area caused to more viscosity and this situation will increase the time of reaching to target. So droplets can move off target easily. Table 2 showing effects of wind on different size of spray droplets.

As we mentioned before droplets which have 50 and lower micron diameter can not be controlled for drift. Although usually applications don’t need very small droplets, we need small droplets at insecticide and fungicide applications for having better penetration into plant canopy and for better coverage. Beside these kind of advantages of smaller droplets, they will be very open to drift risk.

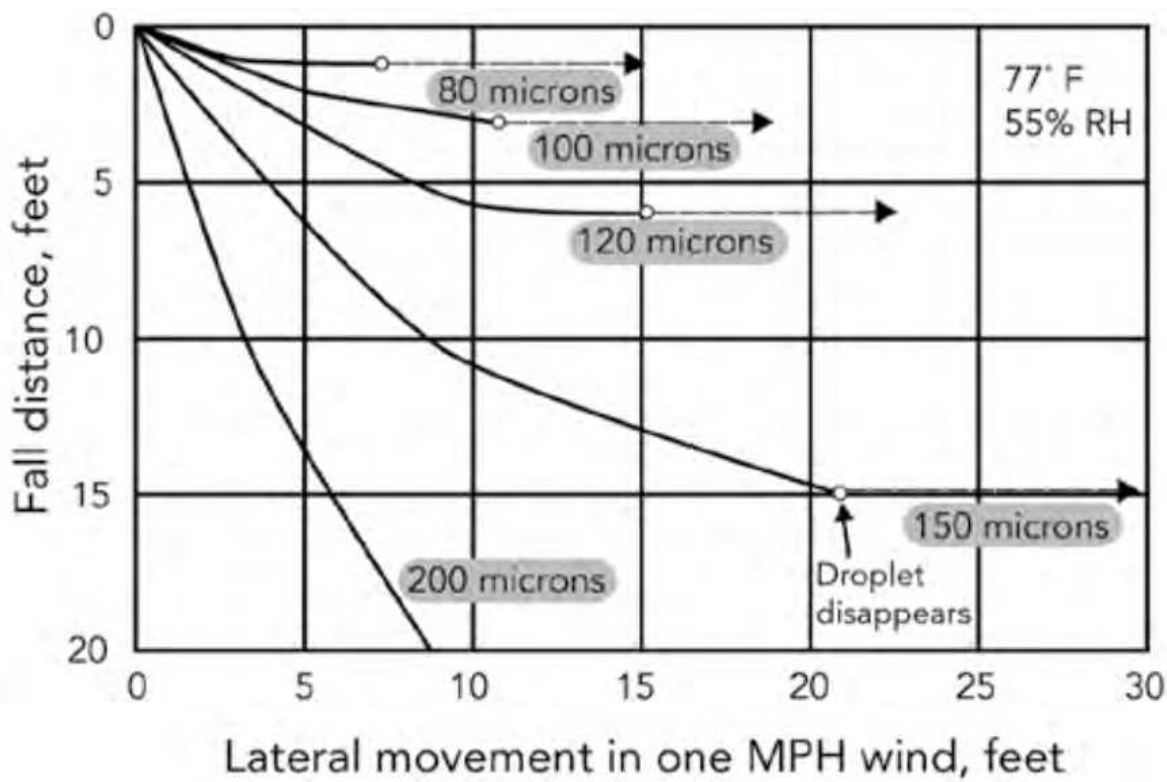


Table 2. Lateral movement of water droplets (Hofman et al., 1986)

3. Drift factors

Spray drift is being affected by environmental conditions and application features. Droplet size, wind speed, climatically conditions, application tools and methods are important factors to determine amount of droplets which can be sent to target surface (Robert E. Wolf, 2000). Adjustment of these factors will increase the efficiency of spraying and this also mean drift will be reduced. General reasons of spray drift can be listed like below :

- Characteristic features of pesticide solution (like viscosity and evaporation characteristics)
- Weather conditions (wind speed, wind directions, air stability)
- Droplet size
- Travel speed
- Nozzle type
- Boom height
- Spray pressure
- Nozzle spacing
- Attention and talent of operator

3.1 Nozzle type

Spray droplets are produced from nozzles in different ways. A flat-fan nozzle; forces the liquid under pressure through an elliptical orifice, and the liquid spreads out into a thin sheet that breaks up into different-sized droplets. A flood nozzle; deflects a liquid stream off a plate that causes droplets to form. A whirl-chamber; nozzle swirls the liquid out of an orifice with a circular motion and aids the droplet formation with a spinning force.

Different types of nozzles have effect on drift because of their different orifice size and outputs. Nozzles must be choose professionally for different applications. Choosing right nozzle for right application is first step of reducing drift.



Fig. 1. Effects of nozzle type on the droplet size
(<http://www.yorktonaircraft.com/documents/drift.pdf>, 2005)

3.2 Driving speed

Spraying usually performed by tractor mounted sprayers. Travel speed are usually between 8 and 10 km/h and trying to keep certain height. Faster travel speed have effect on drift occurrence. It will increase pressure of air on spraying nozzle and this pressure will cause finer droplets (T. Wolf, 1997).

3.3 Spray pressure

Spray pressure influences the size of droplets formed from the spray solution. The spray solution emerges from the nozzle in a sheet, and droplets form at the edge of the sheet. Increased nozzle pressure causes the sheet to be thinner, and this thinner sheet will break into smaller droplets than from a sheet produced at lower pressure. Also, larger orifice nozzles with high delivery rates produce a thicker sheet of spray solution and larger droplets than smaller nozzles.

3.4 Boom height

There is a direct relationship between drift and boom height. Boom height must be at optimum level related to nozzle characteristics for decreasing drift that is caused by wind. Higher boom height makes droplets very open to spray drift risk (Arvidsson, 1997; Miller, 1999).

3.5 Nozzle spacing

Nozzle spacing have a direct effect on spraying pattern with boom height. Spray angle is the angle formed between the edges of the spray pattern from a single nozzle (Fig.4). Nozzles with wider spray angles will produce a thinner sheet of spray solution, and smaller spray droplets than a nozzle with the same delivery rate but narrower spray angle. However, wide angle nozzles are placed closer to the target for proper overlap than narrow angle nozzles and the benefits of lower nozzle placement offsets the disadvantage of slightly smaller droplets for drift reduction.

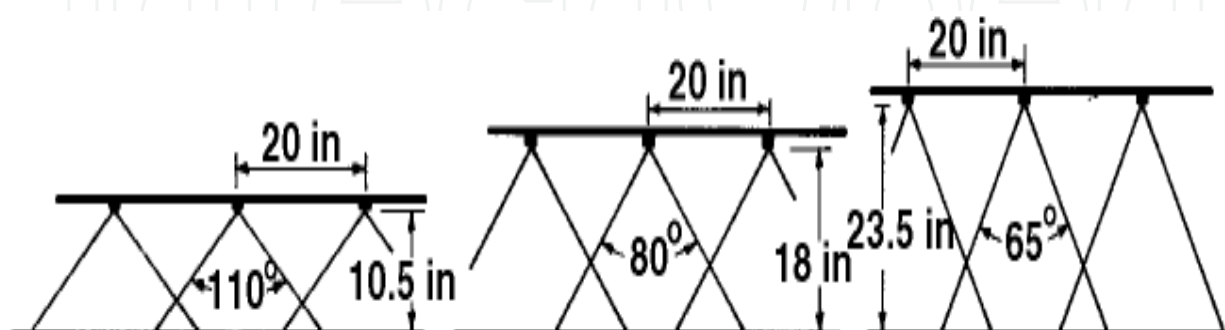


Fig. 2. Influence of nozzle spray angle on nozzle height for proper overlap to give uniform spray distribution.

The angle of nozzles relative to direction of travel can influence drift from aerial application. Because of greater wind shearing when nozzles are pointed into the wind, nozzles pointed toward the direction of travel will produce smaller droplets than nozzles pointed back. The smallest droplets are produced from nozzles 45 degrees forward of vertical, while the largest droplets are produced by a straight-back (90 degree) orientation. Droplet size becomes progressively larger as the nozzle is rotated back from 45 degrees forward to the straight-back position.

3.6 Weather conditions

Air condition have an critical effect on spray drift. Microclimatic features of spraying field and much more aerial factors can caused drift. These factors;

- Wind speed and direction
- Relative humidity and temperature
- Air stability

Factors that are mentioned above have especially important effect on drift of droplets under 150 microns. Elimination of fine droplets will decrease whether conditions effect on drift mechanism.

3.6.1 Wind speed

Wind speed is most important meteorological factor on spray drift and it have a direct effect on drift. Increasing of wind speed will increase drift, proportionally. Drift will be uncontrollable at over 10-12 km/h wind speed and spraying must be finished over that wind speeds (R. Frank, 1988).

Wind speed will show some variability at different periods of day. Because of that spraying must be done at stabile air conditions. At the other hand so lower wind speeds or no wind conditions can cause a spray drift too. As it can be understand from that, spraying must be

done at constant wind speed and direction conditions. Early time of morning and night will be proper choice for spraying (T. Wolf, 1997).

Also nozzle pressures must be adjust into values which are well-matched with wind speed. There is an inverse proportion between nozzle pressure and wind speed. When the wind speed increase, nozzle pressures must be decreased related to producers catalogs. When wind speed reaches 3 m/second, nozzle pressure must be decreased and beside that orifice of nozzle must be greater too. With these adjustments drift risk will be reduced. Wind measurements must be taken continuously during spraying application and needed adjustment must be performed immediately.

3.6.2 Wind direction

Wind direction must be considered as much as wind speed. Especially if there is sensitive plants around the spraying field, drift must be taken under control. As a result of that wind direction must be monitored continuously and there must be a minimum 30 meter buffer space. This buffer zone can be sprayed when the wind direction has changed.

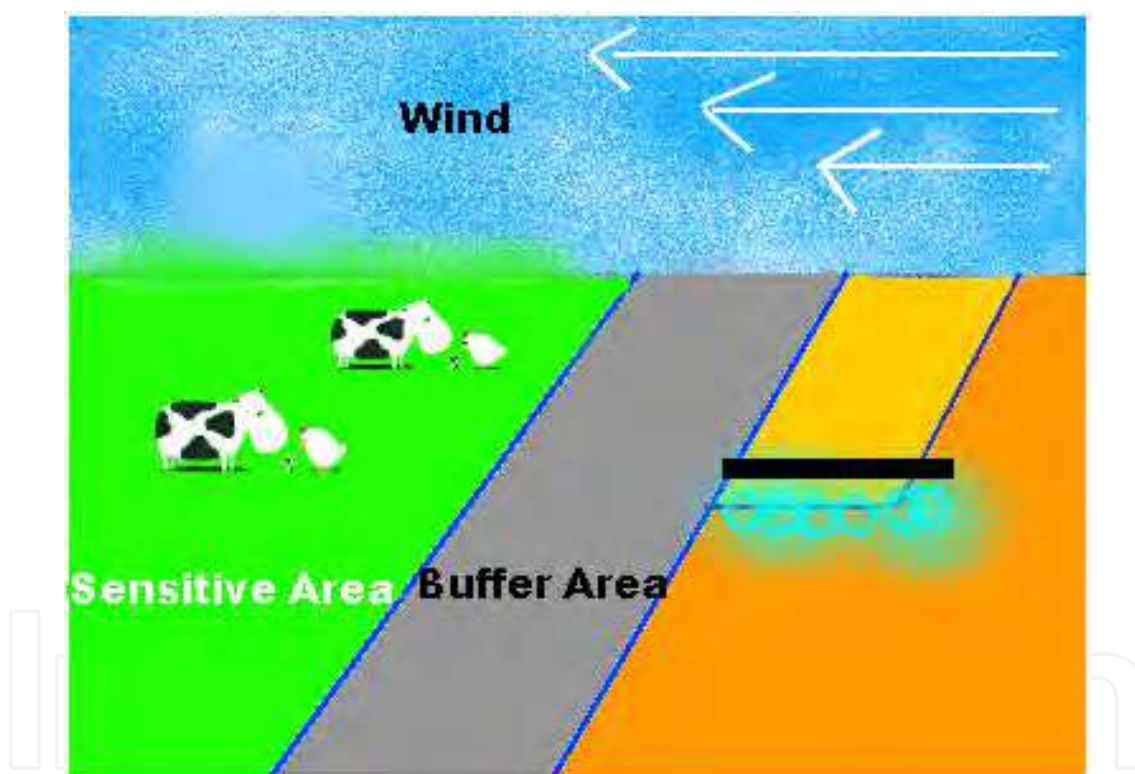


Fig. 3. Buffer area for protection of sensitive area

3.6.3 Relative humidity and temperature

Spray droplets start to dry and evaporate just right after sprayed by air temperature and relative humidity. Drying period is directly affected by air temperature and relative humidity. Studies showed drying period can be decrease four times. Faster drying period will decrease droplet size and mass during its travel at the air. This will increase risk of spray drift (T. Wolf, 1997).

Relative humidity and temperature are factors that affecting drift together. Usually they are not as important as wind speed, but at some geographical places and meteorological

conditions they became significantly important. Spray droplets are transported by air and because of that when water content of spray evaporated, this will cause to loss of mass with size and will make droplets tended to drift. Drift risk will be more when the size loss increased. Amount of evaporated water content of spray droplet is related to relative humidity and temperature.

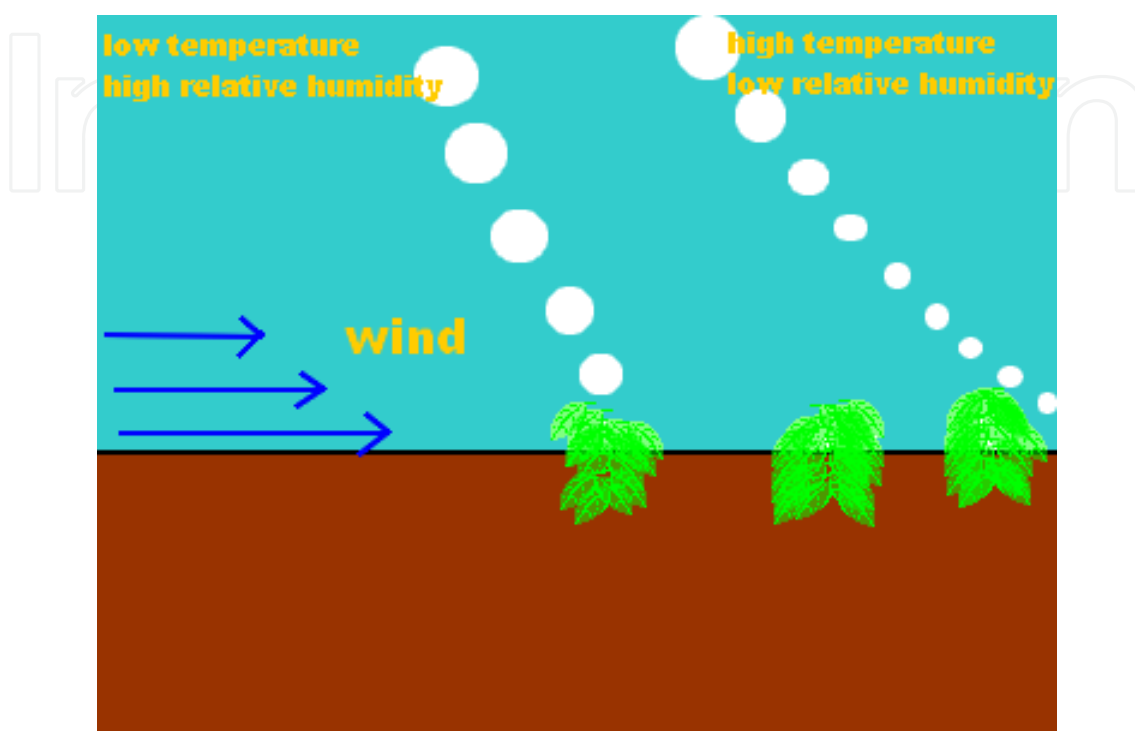


Fig. 4. Effects of temperature and relative humidity on drift
(<http://www.yorktonaircraft.com/documents/drift.pdf>, 2005)

When the temperature increased, relative humidity will decrease and this will make easier evaporation of droplets.

When the evaporation happened, droplet size will decrease, air travel time and as a result of that drift risk will increase. This losses will decrease at early hours of night and day because of cooler air conditions. Temperature also can evaporate spray droplets on the target surface. Temperature have also indirect affect on air turbulence, air stability and inversion. Studies showed fine droplets are tended to vaporize drift when the temperature is over 25 °C and relative humidity is low. Coarse droplets nozzles have to be choosed if it has to be sprayed at high temperature conditions.

3.6.4 Air stability

Air stability is another important factor for controlling drift. Air temperature is decreasing 12.2 °C at every 305 meter in normal meteorologic conditions. Cool air is tend to sink and this makes a vertical mix with hot air.

Athmosphere is not stable at sunny days because air is more hot at near to ground than higher layers of air. Hot air will rise in the cool air and this will make turbulence at unstable air conditions. Droplets in the air will move easily laterally and vertically and adjacent air layers will mix .This situation will caused to drift and also clean air will reduce concentration of pesticide (T. Wolf, 1997).

Under stable air conditions while ground becoming cool, warm air layer will take cool air layer underneath. At this condition droplets in cool air can move only laterally. This is called as temperature inversion. Spray cloud can keep density for a long time at inversion conditions.

However much stable air conditions are not fit for spraying too. Because when the wind speed is increased, high density spray cloud will be very opened to drift risk (T. Wolf, 1997) Atmospheric inversions are usual part of daily atmospheric cycle. Occurring in the early morning hours when the ground is cooler than the air layer just above it. Inversions tend to dissipate during the middle of the day when wind currents mixed the air layers. Because of that applicators must wait until late afternoon or early evening for spraying.

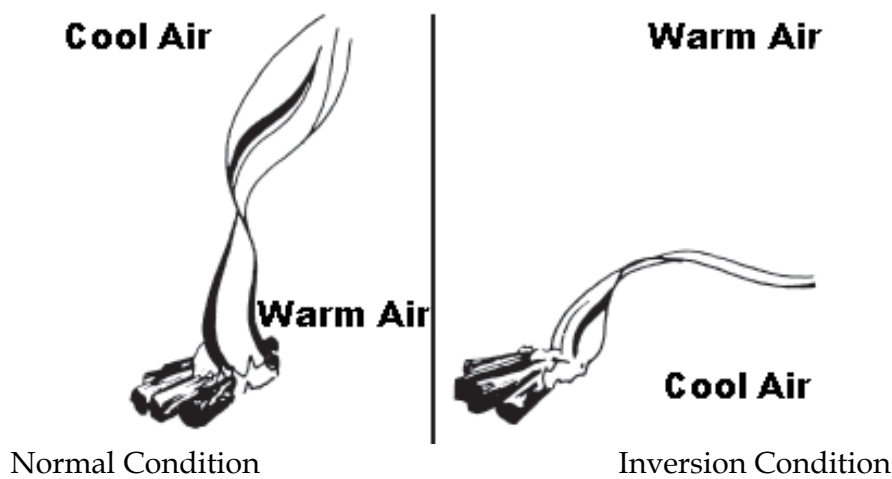


Fig. 5. Atmospheric Inversion dynamics

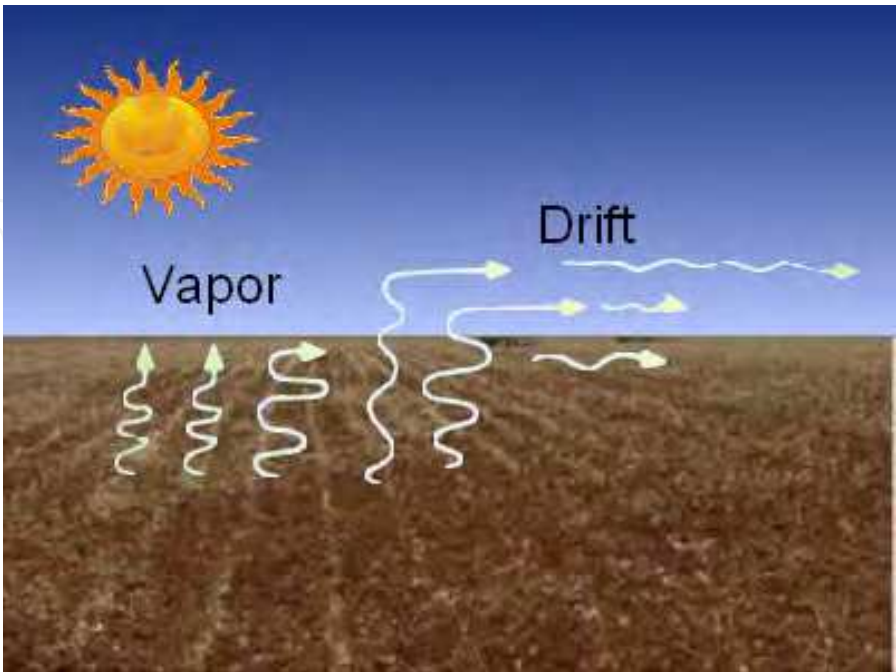


Fig. 6. Athmospheric Inversion

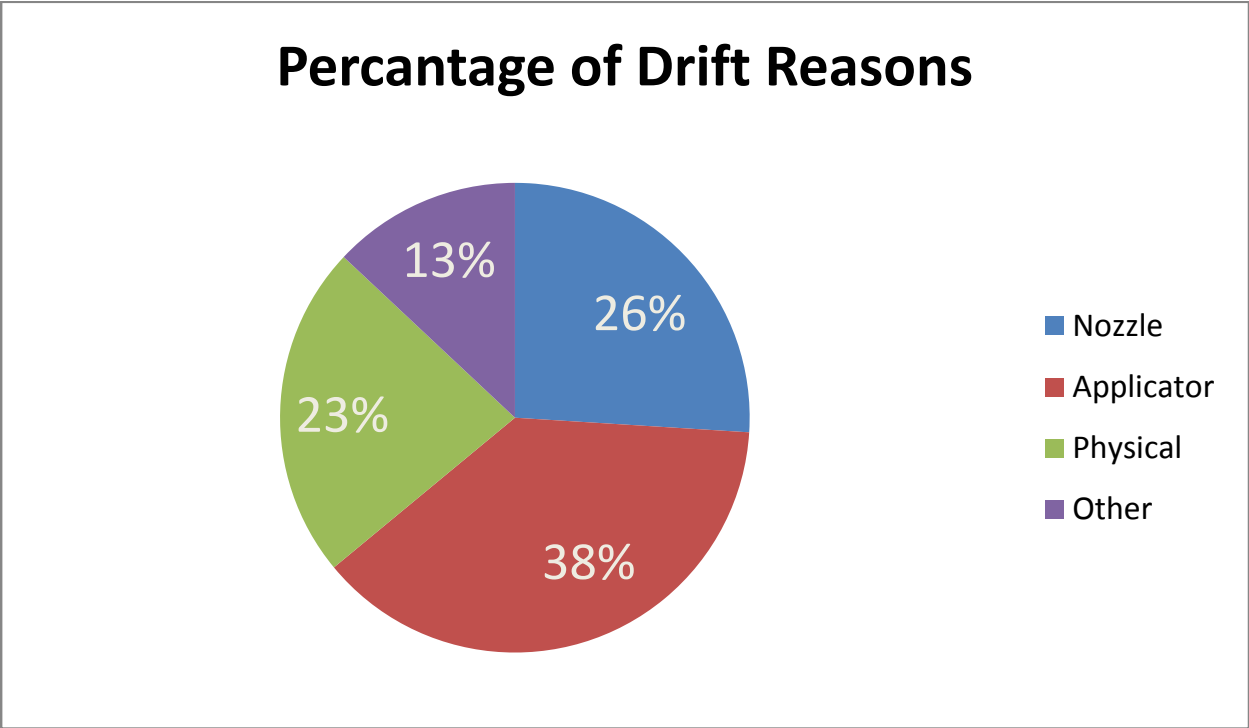


Table 3. Percentage of Drift Reasons (*agsafety.tamu.edu/Programs/Ag-Chemical/drift.ppt*)

4. Drift measurement techniques

There are five types of spray drift sample are commonly used for measuring

- droplet sedimentation onto horizontal surfaces
- airborne concentrations at defined points downwind of an application site
- a total quantity of airborne spray passing through an imaginary frame at some distance downwind of an application site
- using sensitive plant specieces which are placed at defined distances at downwind
- laser based sampling instruments

Ground sedimentation; is very usual method for measuring spray drift. This method is based on measuring spray sedimentation on horizontal surfaces which are positioned at downwind of and application site. Some rules have to be done while using of this method:

- Sampling surfaces are horizontal and they must not be block by any of object like vegetation.
- Adequate size and spatial distribution of samples must be used. Minimum 1000 cm² total area is an international standard for field experiments.

Evaluation of drift can precisiuously controlled under laboratory conditions. Because all parameters can be controlled and this will be caused to a simple relationship between drop size/speed. But in practice field variables results a complex relationship. For reducing the complexity, all meteorological parameters have to be recorded at drift measurement field. To minimise the impact of field variables such as wind turbulence, the experiments are sited in open areas away from hedges/trees.

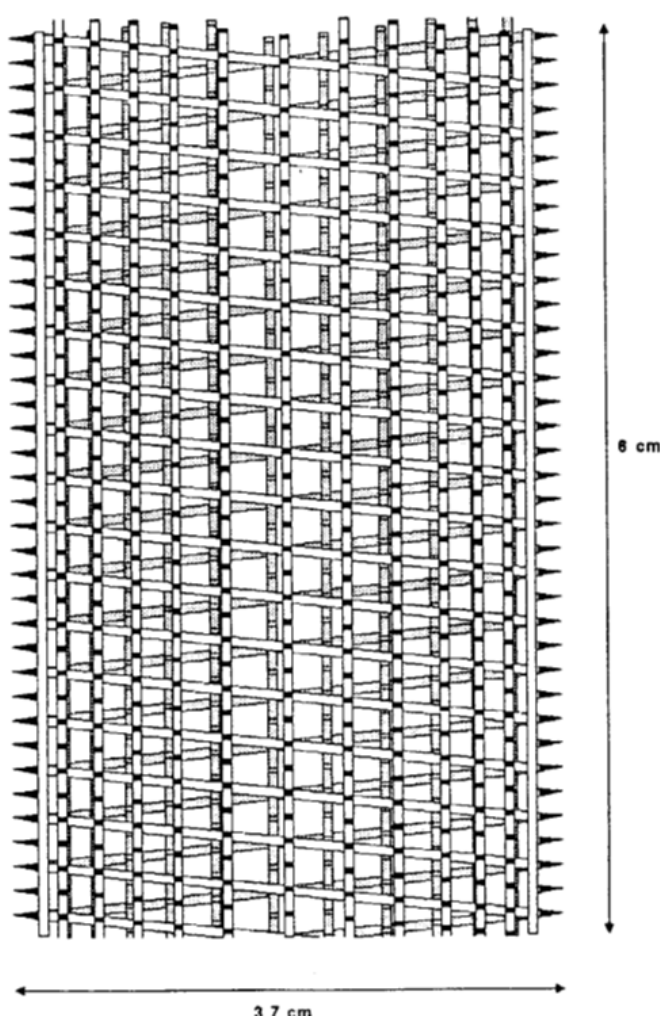
Results of sedimentation can be used at risk assessment for such as protect surface water sources and defining buffer zone sizes (Anonymous, 2003).

Airborne concentration measurements; can be performed with high volume air samplers, cascade impactors or rotary samplers. Small droplets can be collected efficiently with this method. But the main disadvantage is high power requirements and complexity of the system. (Anonymous, 2003)

Airborne spray flux; evaporation will reduce the size of spray droplets. Because of that very small droplets (10-100 micrometer) must be quantified with samplers. Airborne spray drift flux at downwind can be sampled by below methods:

- isokinetic air sampling; at this method a thin-walled sampling tube can be aligned with the air flow direction.
- passive collection surfaces; at this method spray droplets are collected by some lines, rods, cotton and woollen threads, pipe cleaners etc. (Anonymous, 2003).

Drift targets, drift sampler targets have to be enough big to collect sufficient data and at the other hand have to be enough small to not block passage of air. Also it must be effective for trapping very small inflight drops. Targets are positioned at three dimensions to describe size and density of spray cloud at enough points and positions. Usually 10 m height masts are used at 200 m away from downwind for sampling. That masts are built up from 2 mm wide plastic tubes, which are mounted vertically and horizontally, permit sampling at all points and make an imaginary line for sampling spray cloud. At some studies researchers use complex target shapes for increasing small drop impaction.



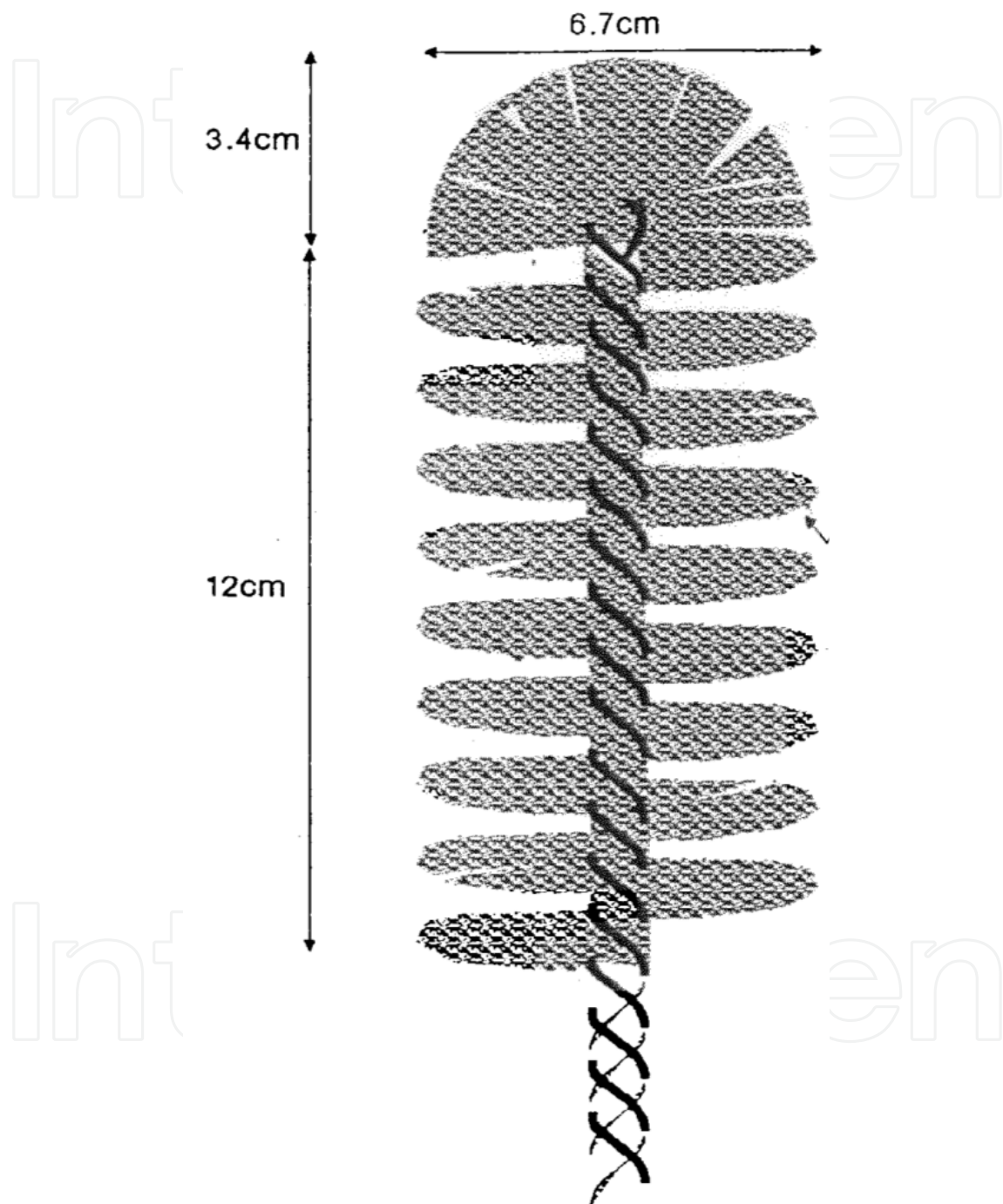


Fig. 7. Some different drift samplers ([http://www.comam.com.br/literatura/Techniques for measuring Spray Drift - Hardi.pdf](http://www.comam.com.br/literatura/Techniques%20for%20measuring%20Spray%20Drift%20-%20Hardi.pdf))

Reducing the variability in deposit on the drift collectors and increase measured values, several swaths may be sprayed using the same tracks (for comparative studies) or sequential ones (for field drift losses)

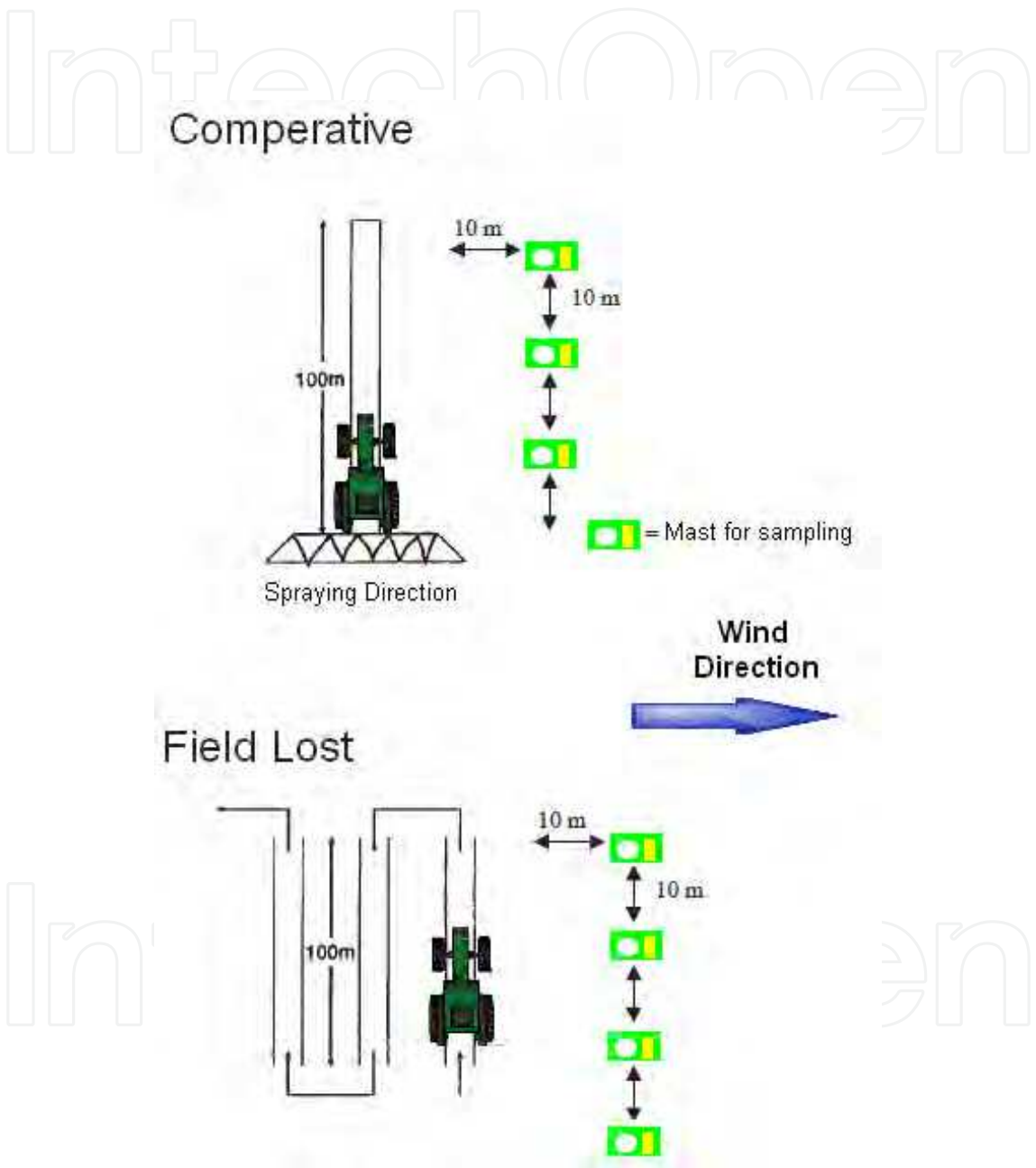


Fig. 8. Typical mast position for spray drift measurement

The distance sprayed up to and beyond the sampling targets needs to ensure the spray cloud is fully developed before, and slight variations in wind direction are considered. Minimum 100 m distance is typically used at most of studies. During and after the spraying wind speed and direction have to be recorded. Also nozzle types, boom width and height must be noted before the application.

Deposits are usually assessed by active ingredients or tracers like colorimetric or fluoremetric dyes. Beside its certain results of using active ingredient is so difficult. Because extracting the results takes so much time and measuring also preparing the process is relatively difficult. These situations are limited using of active ingredients at large number of samples.

Tracers are preferred at most of studies but they have some limitations also. They can interfere from formulation and this will reduce certainty of measurements.

Water sensitive papers can be also used for measuring spray drift. But they must be used very carefully while interpreting the results. Drop numbers, size and cover rate can be extracted from water sensitive papers.

4.1 Estimation of drift potential

An empirical model for predicting spray drift, is developed by Sarker and Parkin at 1995. At this study, they used wind tunnel measurement of spray drift to describe an empirical correlation model of most important parameters of spray drift. They achieved this purpose by using dimensional analysis. The following equation was developed by them:

$$Dp = 1.612 \times 10^{-3} (C_{dis})^{5.973} \left(\frac{h}{D}\right)^{-0.180} \left(\frac{h}{x}\right)^{1.0451} \theta^{-0.2664} \left(\sqrt{\frac{h}{Q}} \frac{u}{Q}\right)^{1.618}$$

D_p = drift potential

C_{dis} = coefficient of discharge, which is a measure of the energy loss through an orifice. C_{dis} is calculated from:

$$C_{dis} = \frac{Q}{A \sqrt{\frac{\Delta P}{\rho}}}$$

where Q is the discharge ($\text{m}^3 \text{s}^{-1}$), A is the orifice area (m^2), DP is the pressure drop across the nozzle and ρ is the fluid density

h = nozzle height (m)

D = equivalent diameter of the orifice (m). D is calculated from

$$D = 2 \sqrt{\frac{A}{\pi}}$$

where A is the orifice area (m^2).

x = downwind distance (m)

q = the angle in the vertical plane that the spray nozzle makes to the airstream. If $q = 0^\circ$ the nozzle is fully aligned with the airstream. The singularity in the model caused when $q = 0^\circ$ can be avoided by using $q = 2^\circ$ for this setting.

u = wind speed (m s^{-1}); the wind speed was varied between 1 and 3 m s^{-1} in the experiments.

Q = discharge ($\text{m}^3 \text{s}^{-1}$)

5. Common ground spraying equipments

There are different kind of equipments for reducing drift . In general view an equipment which is producing coarse droplets will reduce drift risk. Droplet size can be adjusted easily by changing nozzle type and size. Equipments must be choose for reducing of fine droplets within spraying pattern. Also wiper applicators can be used at sensitive plants and they will prevent the drift risk. There are four basic type of sprayers for ground applications.

Air assisted sprayers; are equipments that can be mount on tractor or pull by tractor. Independent and mechanically controlled air flow is being used for spraying. Drift risk is very high because of air flow.

Boom sprayer; this sprayers have very wide variety of equipments. Spraying are doing my spray nozzles which are arranged as a row on a boom. Boom height can be adjusted related to nozzle specifications. Spray drift can be minimized by appropriate height adjustment of boom for every different applications and nozzles.

Boomless sprayers; have nozzle groups or spinning disc which can be spray target area. As a result of that, there is no need to boom at this kind of sprayers. Groups of nozzles usually are tend to produce bigger droplets and this is reducing drift risk also. Spinning disc will produce small droplets and this will increase drift risk also.

Wiper systems; have mechanic contact with target surface. Drift risk is so less at this kind of application because it is depending on rubbing to surface, not spraying.

Electrostatic sprayers; are using electrostatic charging technical. Liquid spray droplets are charged negatively. Droplets and plants have opposite charge and they attract each other as a result of physical phenomenon that explain attraction of opposite electrical charged particles. The charged droplets are attracted to the spray target and are able to wrap around objects. There are three different types of electrostatic spraying. These are corona, contact and induction electrostatic spraying methods. (E.Dursun et al, 2005)

6. Techniques for controlling drift

There must be considered some issues for reducing drift risk as well as choosing appropriate equipments.

- a. It is very important to choose appropriate nozzle which can have better coverage on surface with optimum size droplets. We also have to consider the place of application while choosing nozzle. For example if we are spraying a place near to ways, using a nozzle which can produce uniform droplets will be more useful.
- b. Reducing the distance between target and nozzle is useful for decreasing drift risk. But coverage will be insufficient if boom is so close to target. .because of these situations distance between target and nozzles must be adjust and monitor continuously. Any change in the height of boom spraying parameters like pressure and flow rate must be calibrated again. Changes must be applied carefully and all of them must be appropriate with manufacturer's specifications.
- c. Operators must be monitor nozzles for physical blockage. Nozzles should be cleaned and replaced if necessary. Calibration of nozzles will be useful for long life usage.
- d. High pressures must not to used at spraying applications. High pressures will caused to produce fine droplets and this will be increased drift risk.

- e. Some additives can be used at spraying chemical for reducing drift. These additives can be increased or decreased viscosity and density of droplets. Also they can effect volatility of spraying chemical. So additives can be used for preventing drift risk.



Fig. 9. Low drift nozzles (Spraying Systems Co.)

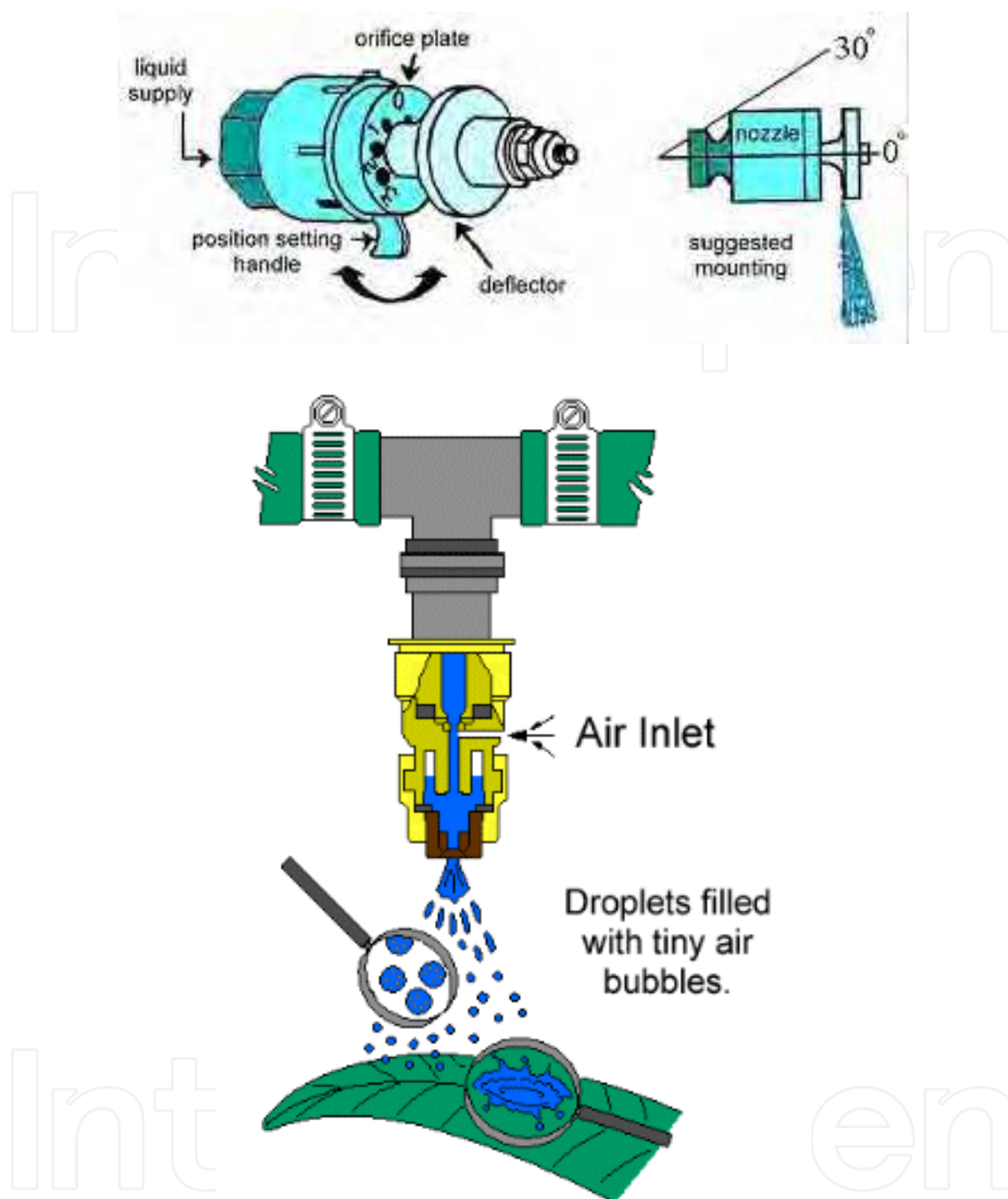


Fig. 10. Low drift nozzles (Greenleaf Tech., Covinton, LA)

6.1 New nozzle technologies

Low-drift nozzles

Production of low-drift nozzles become more important as a result of worldwide attention on preventing drift. When compared with flat nozzles, low-drift nozzles can produce more coarse droplets at same spraying pressure and output. Using of these nozzles decreasing amount of droplets that under 200 μm at %50-80 rates. As a result of bigger droplet size, drift risk is being decreased. (E.Dursun et al, 2005)

Pneumatic nozzles

Air and liquid pressure can be adjusted independently at this kind of spraying nozzles and we can control droplet size as a result of that adjustment.

Spinning disc nozzles

We need 10-50 μm droplets at insecticide and fungicide applications. Spinning disc nozzles are good solution for that kind of needs.(Matthews, 1992).

CP nozzles

Nozzle orifice can be adjusted by the adjustment mechanism on the nozzle. Required nozzle orifice diameter can be adjust by that feature.

Twin nozzles

These nozzles can be used at application which need good coverage. They also have advantage for penetration too. (Çilingir ve Dursun, 2002).

Multiple nozzles

This kind of nozzles have group of three-four or five headers which nozzles can be mounted on them. Different kind of nozzles can be mounted on these headers. So choosing a right nozzle for different spraying application will be easier.

7. Suggestions

Better understanding of new technologies at spraying will help to reduce drift. Droplet size, understanding of droplet spectrum and weather conditions have effect on these reduction.

Sufficient knowledge about spray drift, factors of spray drift and application tools will make a better control on drift management. Plant protection and drift management must be balanced. For proper and successive spraying application variables below must be considered;

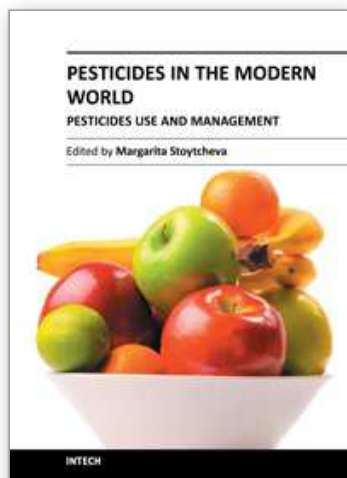
- Spraying pressure
- Nozzle type
- Application rate
- Boom height
- Travel speed
- Wind speed
- Air temperature
- Air stability
- Relative humidity
- Enough buffer space from sensitive areas
- Directives of pesticide producer

Drift is absolutely unwanted situation at anyplace and anywhere;

- Drift cause a decrease at efficiency at both application and economical.
 - Drift can cause damage at sensitive crops which are near to application area.
 - Chemical residues at food products will reduce product quality.
 - Can caused to air and water pollution.
 - Drift can make risk for human and animal health.
 - Less chemical residue on target surface will decrease efficiency of spraying application.
- This will increase total costs.

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Pesticides in the Modern World - Pesticides Use and Management

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This book brings together issues on pesticides and biopesticides use with the related subjects of pesticides management and sustainable development. It contains 24 chapters organized in three sections. The first book section supplies an overview on the current use of pesticides, on the regulatory status, on the levels of contamination, on the pesticides management options, and on some techniques of pesticides application, reporting data collected from all over the world. Second section is devoted to the advances in the evolving field of biopesticides, providing actual information on the regulation of the plant protection products from natural origin in the European Union. It reports data associated with the application of neem pesticides, wood pyrolysis liquids and bacillus-based products. The third book section covers various aspects of pesticides management practices in concert with pesticides degradation and contaminated sites remediation technologies, supporting the environmental sustainability.

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