

Calibration of sprayers

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Summary

The origin of the word “calibration” is the matching of the bullet size to the size of the canon barrel - in other words a preparation that is necessary to ensure a desired well defined result.

For spraying, calibration is necessary to ensure targeted, optimal use of plant protection products, minimum risk to the crop, consumer, and environment and to avoid excess spray liquid at the end of the spray job.

This paper describes a practical method for calibration of field crop sprayers orchard sprayers and hand held sprayers as well as some aspects of calibration that may need further discussion and clarification: So far there are no well documented general answers telling at what wear rate nozzles should be changed, how chemical injection systems can be calibrated efficiently and safely.

Introduction.

In practice sprayer calibration is a method to check end ensure that:

1. The volume of spray liquid mixed in the spray tank will fit exactly with the area to be treated - leaving no left over volume to be disposed. Calibration will prove if:
 - The nozzles are worn a little and the pressure needs to be readjusted.
 - The nozzles are worn out and need to be changed.
 - The speed is correct. The tractor speedometer may be incorrect (dependent on e.g. tyre size).
 - The pressure gauge is incorrect or there is a pressure drop from gauge to nozzles that needs to be accounted for.
2. The nozzles are performing well (no damaged nor blocked nozzles).
3. The boom is adjusted correctly – correct height and in level.
4. the sprayer is in good shape and with no leakages.
5. Precise dose rates of plant protection products can be calculated and applied.

There is so far no standard for sprayer calibration, what parameters must be included in the calibration, how it should be carried out or what tools and accuracy is recommended.

The following describes a basic, low tech method aiming to check the sprayer regarding the above mentioned aspects.

However there is also a more holistic point of view from which a full calibration preparing the sprayer for the desired well defined result would include choice of droplet energy (a result of nozzle size, type and air assistance) adapted to target and weather conditions like wind speed, temperature and humidity. Traditionally the nozzle selection is dealt with separately from what is normally included in the calibration procedure. This paper suggests that future calibration encounters the total spray account as an aim to optimise on-target deposit and hereby minimising any off-target deposit, as described in figure 1 (Jørgensen and Witt 1997).

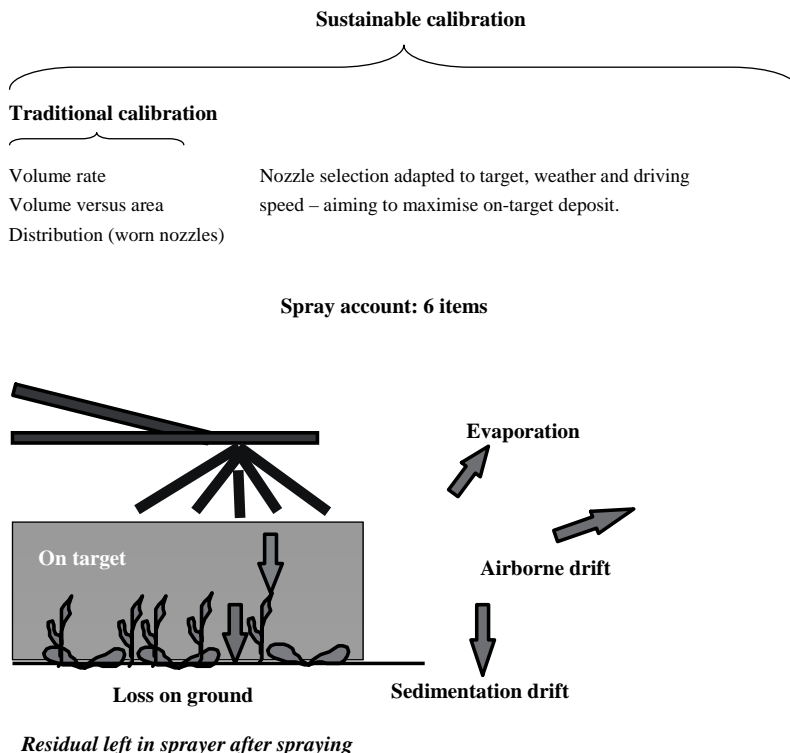


Fig. 1 The 6 items in a spray account describing where the spray liquid may end up. After Jørgensen and Witt 1997

Most sprayer manufacturers have described a calibration method in order to control the spray volume (l/ha). As many European countries require that sprayer operators pass an exam to be licensed to apply plant protection products there are also several books and leaflets giving the relevant instruction in how to check that a sprayer is operating safely and efficiently – in Denmark the official publication is called “Handbook for sprayer operators” (Spliid et al. 2008).

The following description of calibration is based on Hardi International’s booklet “Spray Technique” available from the internet in 10 languages (Hardi International 2002). Any description of a calibration procedure will reflect decisions regarding “how often should calibration take place” and “how much nozzle wear can be tolerated”, however reasoning and test results that may lie behind are rarely presented.

Field sprayer calibration – checking volume rate

Always start with a clean sprayer with clean water in the tank. For safety reasons nozzle checking should take place over an area covered with grass or other vegetation in the field. Always use gloves when touching the sprayer even though it has been cleaned. Personal Protective Equipment [such as gloves, coverall, boots] is intended for precautionary use only. Remember to take off gloves and any other Personal Protective Equipment – especially if contaminated - every time you enter the tractor.

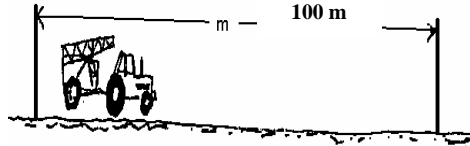
Every time a sprayer is calibrated make records of: tractor, tyre size, speed, gear, RPM, nozzle type and size, calibration pressure, theoretical and measured nozzle flow (l/min) and volume rate (l/ha).

A. Choice of spraying parameters:

The agrochemical label often suggests an all round efficient volume rate – l/ha. However own experience, special weather conditions and local research or need for high capacity may often lead to choosing an alternative - often lower - volume rate. Also driving speed can be very individual – some farmers look for high capacity through higher driving speed -others use a low speed to minimise drift and increase crop penetration. For uneven ground or simple boom suspensions lower forward speed is recommended. Often volume rate and driving speed are decided first – then the nozzle choice is limited to the possibilities within the accepted pressure range (normally 2 to 2.5 bar for conventional nozzles).

B. Check driving speed:

- Measure 100 meters. It may be useful to have some ‘permanent’ markers that are located in a convenient place (in a field or field like conditions).
- From the table in the tractor you find the gear to achieve the speed you want at a given rpm.
- Drive the measured distance (with a ½ filled tank) and measure the time.
- Calculate the speed:



$$\frac{\text{Distance driven (m)} \times 3.6}{\text{Time (sec)}} = \text{km/h}$$

- If the speed check does not lead to the desired speed either choose another gear and check speed again or change the rpm to reach the required speed:

$$\frac{\text{RPM from speed check} \times \text{required speed (km/h)}}{(\text{km/h}) \text{ from speed check}} = \text{New RPM to get the required speed*}$$

*The pto-RPM should not exceed 540. If agitation is still acceptable the pto, RPM can be reduced down to about 400 as a minimum (that is – 25%). Some tractors and sprayer pumps run at around 1000 rpm at the PTO in stead of 540 rpm.

C. Calculate the required nozzle flow and choose nozzle size:

$$\frac{\text{Checked speed (km/h)} \times \text{Water rate (l/ha)} \times \text{nozzle spacing (m)}}{600} = \text{Flow for each nozzle (l/min)}$$

Find a suitable nozzle size in a nozzle catalogue

D. Check liquid system

- Always use clean water for calibration.
- Mount the chosen nozzles on the boom.
- Turn on the sprayer and spray at minimum 8 bar whilst you check the liquid system for any leakages.
- Check the agitation
- Nozzle performance. Always take a good look at the whole boom performing – try to have the sun behind the nozzles – and see if any nozzles are damaged or maybe partly blocked. “Stripes” in the spraying pattern is a sign of wear, and all nozzles should be changed.

E. Check nozzle output

- Set the pressure.
- Adjust even pressure valves on all boom sections.
- Measure the nozzle output for one minute.
- Repeat - measuring at least 2 nozzles for every boom section.
- Calculate average nozzle output.



If the nozzle output is not that required (and the nozzles are not worn more than 10 %) pressure can be readjusted:

$$\left(\frac{\text{New output (l/min)}^2}{\text{Measured output (l/min)}} \right) \times \text{Measured pressure} = \text{New pressure}$$

$$\frac{600 \times \text{measured nozzle output (l/min)}}{\text{Nozzle spacing (m)} \times \text{speed (km/h)}} = \text{l/ha}$$

F. Based on the size of area to be treated the volume of the total spray mix and how much plant protection product to add can now be calculated.

Field sprayer calibration – checking nozzle wear and uniformity

Wear test – all nozzles:

- 1 Fix a new nozzle on the boom (same brand, type and size as the ones you want to check). This is your reference nozzle
- 2 Check the flow of this nozzle at your spray pressure.
- 3 Calculate the maximum tolerated average flow
= flow for new nozzle + 10 % = l/min for new nozzle x 1.10
- 4 Check all nozzles at 3 bar
- 5 Calculate average. Sum of nozzle flows / number of nozzles

Uniformity

1. Calculate the maximum and minimum accepted limits for individual nozzle flows: +/- 5 % of the average measured above.
2. Check that all measured flows for the individual nozzles are within the limits. If one or more nozzles have higher deviations than + or – 5 % all nozzles must be changed.

Wear test – quick-test during the season:

A quick check-up during the season can be useful (but it still remains very important to carry out the full nozzle test for both wear and uniformity as specified at least at the beginning of a season). Measure the flow rate for a sample of nozzles – could be 2 nozzles per boom section - and check that individual flow for the measured nozzles does not exceed the worst case situation of more than 10% average wear plus a further 5 % deviation allowed for individual nozzles. Maximum wear (10 %) + maximum deviation (5 %) = 15 % meaning that 15 % increase in single nozzle output can be tolerated in the quick-test.

When to change to new nozzles:

When the average nozzle flow has increased by more than 10 % compared to the flow from a new nozzle – all nozzles must be changed to new ones. Does one or more nozzles deviate more than +/- 5 % compared to the average flow, it is sufficient to shift these nozzles if the average nozzle flow is increased less than 5 % compared to new nozzles. If the average flow has increased by more than 5 % and one or more single nozzle flows deviate more than +/- 5 % ALL nozzles on the boom must be changed.

How often must a sprayer be calibrated?

Before spraying with a new set of nozzles, new volume rate, new speed, new tyres, new pressure or any new field or equipment conditions:

- Check driving speed.
- Check nozzle flow and pressure.

Once a year (and before inspections) Hardi recommends a thorough check:

- Check driving speed.
- Check all nozzles.
 - if average output has increased more than 10% compared to new nozzles: change all nozzles.
 - if there is more than +/- 5 % deviation in nozzle output, change all nozzles.

During the season frequent quick-checks are recommended:

- Check 2 nozzles per boom section if one nozzle has more than 15 % increase in flow, change all nozzles.

The basic calibration as described above is based on following assumptions:

- Average nozzle flow (l/min) may not exceed output from new nozzles + 10 %.
- Single nozzle flow may not exceed output from new nozzles + 15 %.

Tools for quick calibration and boom distribution measurement

Many sprayer manufacturers are aware that the formula for calculation of total nozzle flow based on nozzle spacing, driving speed and the wanted volume rate (l/ha) is not very handy in practise. Therefore different aids have been made, like calibration wheels and rulers where the most used formulas are integrated. Also little programmes for PC and PDA are available for free download from some sprayer manufacturers. One of the more advanced examples is Calipilot from Hardi International. The Calipilot offers all necessary calculations for calibration and adding of plant protection product. Also nozzle wear is dealt with. The programme is available from the Hardi homepage.

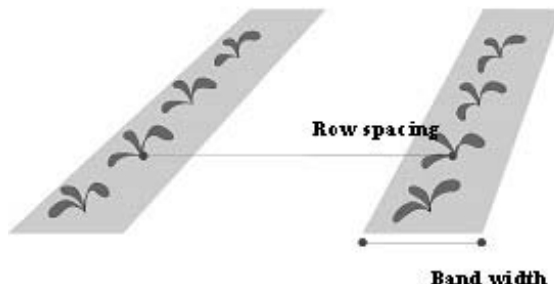
Also more advanced tools that take calibration beyond the crude measuring jug are available: from handheld units for measuring, saving and processing the nozzle flow rates to more or less advanced spray tables, some for simultaneous measurement of nozzles from a boom section and for visualising the distribution to advanced models that automatically read and process data for each 10 cm of a whole boom offering data like coefficient of variation as a description of boom distribution.

Electric control of valves and sprayer computers are making life more easy for sprayer operators – however speed monitors may be faulty either do to errors when setting or if not calibrated to specific tyres. Increase in flow rate due to nozzle wear may be encountered for automatically when setting a wanted volume rate – however the individual nozzles still need to be checked for wear and performance.

Bandspraying - Calibration method

Water volume rates [l/ha] in the treated band:

Label recommendations usually state total water volume rates l/ha, also called broadcast rates. When band spraying, we only want, to apply this broadcast rate in the bands, so instead we call it: l/ha in band.



Check forward speed (as in field sprayer calibration):

Find required nozzle capacity:

$$\frac{\text{l/ha in band} \times \text{band width (m)} \times \text{km/h}}{600} = \text{volume of water [l/min] for the band}$$

Total required water volume:

$$\frac{\text{area of field (ha)} \times \text{l/ha in band} \times \text{band width (m)}}{\text{row spacing (m)}} = \text{total volume required (l/field)}$$

Amount of agrochemical for a tank:

$$\frac{\text{Litres of water in tank} \times \text{chemical dose (l/ha)*}}{\text{l/ha in band}} = \text{chemical per tank (l/ha)*}$$

*or [kg/ha] or [gram/ha]

Chemical injection systems - Calibration method

When spraying with chemical injection there are 2 or more pumps and a main water tank as well as chemical tanks contributing to the total flow. The injection pump can either be a higher pressure or a low pressure pump system (<http://www.freepatentsonline.com/EP1289668.html>):

- High pressure injection pump: can inject chemical close to the spray nozzle as it has sufficiently high pressure to overcome the pressure of the pumped water. Unfortunately, however, this makes calibration of the injection system difficult: any change in the back pressure of the system affects the output of the injection pump.
- Low pressure injection pumps: injects chemical before the sprayer's main pump. This allows accurate calibration of the amount of chemical mixed with the water but is slower acting than the high pressure injection since the chemical is injected a significant distance from the spray nozzle.
PRACTICAL CALIBRATION: measured as l/min of pure chemical flow from the calibration nozzle.

Orchard sprayer calibration – different methods

Some chemical labels indicate what liquid volume per area either the traditional l/ha or Vertical canopy surface (Laubwandfläche) to use – others make the volume rate dependent on crown height. More and more the liquid volume is adapted to a canopy volume (Tree Row volume or Unit Crop Row). Common for all methods is that calibration of liquid flow can be measured as l/min – as illustrated in table 1.

Method “what do we relate chemical dose and water rate to?”	Name of method	Calculate calibration unit: total l/min
Surface area (litres/ha)	(traditional)	$\frac{l/ha \times \text{spray width (m)} \times (\text{km/h})}{600} = l/min$
m crown height (litres/ha/m crown height)	“Crown height rate”	$\frac{l/ha/m \text{ crown height} \times \text{crown height (m)} \times \text{spray width (m)} \times (\text{km/h})}{600} = l/min$
Vertical canopy surface (litres/vt.ha)	Laubwandfläche	$\frac{l/vt.ha \times 2 \times \text{crown height (m)} \times (\text{km/h})}{600} = l/min$
Canopy volume (litres/m ³ or l/1000m ³)	Tree Row Volume TRV	$l/1000 \text{ m}^3 \times \text{crown height (m)} \times \text{crown width (m)} \times (\text{km/h}) \times 16.67 = l/min$
Canopy volume (litres/UCR = litres/(1m x 1m x 10 0m) = “litres/100m ³ ” l/100 m row	Unit Crop Row UCR Distance based	$l/100 \text{ m}^3 \times \text{crown height (m)} \times \text{crown width (m)} \times (\text{km/h}) \times 16.67 = l/min$ $L/100 \text{ m} \times \text{km/h}/6 = l/min$

Tab. 1 Different calibration factors for orchard sprayer calibration.

The following calibration guidance is a summary from Hardi's Mistblowing technique (Hardi International 1993)

Adjusting speed and air volume to orchard canopy volume.

Because forward speed is an influencing factor on the air volume presented to the crop, calibration starts by choosing a combination of air volume (where adjustable) and driving speed.

The theoretical air flow needed (m³/h) for a given application can be calculated as follows:

$$Q \text{ (m}^3/\text{h)} = \frac{1000}{k} * \text{speed (km/h)} * \text{tree height (m)} * \text{spray width (m)}$$

The k value is depending on crop density, for very dense canopies k is 2,5 and if the canopy is very open k is 3,5. Once the required air flow is established, the fan can be adjusted by increasing/decreasing the rotation speed or for some orchard sprayers by changing fan gear or blade angling.

Rule of thumb: At the optimum combination of air volume and speed the spray will only occasionally penetrate through the row.

After establishing the desired driving speed, the speed must be checked by driving in the orchard with the spray tank half filled with water – follow procedure as described for field sprayers.

Orchard sprayer calibration – checking l/min

For orchard sprayers all nozzles must be checked at the desired spray pressure and the total flow (l/min) calculated – or check nozzles on one side of the sprayer and multiply by 2. Then the actual l/ha can be calculated with the formula below – or other calibration units can be deducted from the formulas in table 1.

Normally it is necessary to use a flexible hose to lead calibration water from nozzle to measuring jug.

$$\text{Actual l/ha} = \frac{\text{Total actual l/min} \cdot 600}{\text{Km/h} \cdot \text{Row spacing (m)}} = \text{_____ l/ha}$$

Pressure adjustment if not reaching the aimed flow:

$$\text{New Pressure} = \frac{(\text{New flow})^2}{\text{measured flow}} = \text{_____ bar}$$

Tools for quick Orchard sprayer calibration

Over the years orchard sprayer manufacturers have made different efforts to make calibration easier. Good examples are the calibration wheel and small nozzle selection programme from Hardi International. The latter can be down loaded from the Spanish Hardi homepage.

Using water sensitive paper [WSP] to optimise orchard sprayer spray deposits

The goal in spraying is an even coverage of all target surfaces within the canopy and as little as possible waste above and below the target area. Optimally positioned Water Sensitive Paper within and around the canopy can help assess whether this is achieved and can be used to indicate how best to make improvements to the set up of the sprayer – to maximise on-target and minimise off target deposit.

If there are very few drop impacts on the WSP in the canopy area then try driving slower; a goal that may be best achieved by using a lower tractor gear at the same rpm. Recalibrate speed and recalculate l/ha.

Totally blue papers suggest a too high volume is applied and that run off would be likely on the leaves. If this overdosing occurs then try the use of a smaller nozzle size. Remember to recalibrate flow if changing nozzle sizes and/or pressures.

Totally blue papers can also suggest that too much spray is being lost through the row and is not being retained within the target canopy. Again try smaller nozzles or - when ground conditions allow - a higher driving speed. When spray is not reaching the top of the canopy try:

- a slower forward speed
- replacing the nozzle that is directed at this area with a higher output nozzle
- fitting a double or triple nozzle holder at this point to increase the locally emitted volume

Remember:

Recalibrate speed or l/ha when changing speed or nozzles.

Re-do the WSP check.

Write the exact spraying data on all your records with the relevant WSP.

Keep your calibration sheets ready for the next time you go spraying.

Remember to re-adjust nozzle setting and calibrate when changing from one orchard to another.

Calibration of hand held sprayers – 2 basic methods.

There are many techniques for calibration but only two are described in these notes (Hardi 2001). One method has assumed that there is guidance from the supplier of pesticide on nozzle type, water volumes and also nozzle pressure. The second method assumes very little guidance is available and few instruments to help the operator. Other labels may give dose and water volume rates for small areas

whilst others – only that for a hectare. Some products offer a concentration of solution with general guidance on what sort of target surface coverage should be gained whilst spraying.

General for both types of calibration:

- Fill the clean sprayer with water.
- Check that the sprayer is operating correctly and safely with no leakages.
- Practise spraying at comfortable nozzle height and find your personal walking speed, that you can maintain all though a spray job.
- Spray water on a dry, flat surface at the chosen nozzle height and operating pressure. Measure the width of the spray pattern – do not include tapered edges.

Tools: Stop watch, measuring tape (20 m +), 2 litre measuring jug, and preferably a pocket calculator.

Method 1 – “Spray 1 minute”.

1. Mark out a line at least 100 m.
2. With comfortable walking speed and while spraying correctly, measure distance walked in 1 minute.
3. Spray into container and measure volume of spray emitted for one minute.
4. Calculate l/m², and l/ha:

$$\frac{\text{Volume (l/min)}}{\text{swath (m) * speed (m/min)}} = \text{l/m}^2$$

$$\text{l/m}^2 * 10.000 = \text{l/ha}$$

Method 2 – “Spray 100m²”.

1. Make sure the sprayer is full – place on a horizontal surface and make a mark on the spray tank showing how much water is in the tank.
2. Based on the spray width (see table below) find out how far to walk in order to spray 100m².

100 m²	
Spray width (m)	Spraying distance (m)
0,5	200
0,7	143
1	100
1,2	83
1,5	67

3. Spray 100 m at the practised nozzle height and walking speed.
4. Measure how much water is necessary to refill sprayer to the marking on the tank.
5. To find the volume rate (l/ha) multiply the measured quantity of water (l/100m²) with 10.000 m²/ha.

Handheld sprayers - Tools for quick calibration

Kalibottle

Need: Measuring tape, Kalibottle (instructions on bottle) – No calculator needed!

1. Measure width of spray swath.
2. Mark out 25 m² using a convenient lay-out for this width. For example; if swath width is 0.5 m, a spraying distance of 50 m would be appropriate.

Table: Some useful dimensions for Kalibottle calibration

25 m²	
Swath width	Spraying distance
0.5 m	50.0 m
0.7 m	35.7 m
1.0 m	25.0 m
1.2 m	20.8 m
1.5 m	16.7 m

3. Fit Kalibottle to lance and with bottle hanging vertically from lance, “spray” this marked out area.
4. Application rate is read off the bottle.

Conclusion

The simple method for a traditional field sprayer calibration described above leads to some questions that may need clarification in the process of making a general guideline for calibration:

- How much nozzle wear can be tolerated? Is an average of the nozzle manufacturers statements of maximum acceptable wear rate acceptable in an official recommendation?
- Is it enough to make a visual check of liquid distribution or should the nozzles or the actual boom distribution be tested over a spray table?
- How often should a sprayer be calibrated – and what parameters at what intervals?
- For chemical injections systems a double calibration is needed – one for the grand sprayer liquid system and one for the injection system. For both high and low pressure injection pumps it is a challenge to deal with the cleaning of the measuring jug for measuring concentrated chemical.

The fact that more and more sprayer manufacturers offer manual or IT tools for easier calculation of calibration values indicates that there is a need for simplifying the process.

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