7

Power-operated hydraulic sprayers

Various power-operated sprayers have been designed and range in size from small, hand-carried engine-driven pump units to large self-propelled sprayers (Fig. 7.1). Usually a series of nozzles are mounted along a boom. Small units have a two- or four-stroke internal combustion engine or an electrically operated pump, and are mounted on a knapsack, a wheelbarrow, or a frame for fitting on a vehicle. These small sprayers are mostly used where treatment is not required over extensive areas. Otherwise the tractor-mounted boom sprayers with a pump driven from the power take-off (p.t.o.) is used, especially for field crops, to apply 50–500 litres/ha. Larger-capacity tanks may be mounted on trailers, or as saddle tanks alongside the tractor engine to spread the load more evenly. In Germany, a survey indicated that 42% of large sprayers were mounted on the three-point linkage, while 33% were trailed, and 15% were mounted on a vehicle. Some large sprayers are self-propelled, instead of using the normal farm tractor, but these sprayers are used only on farms with sufficient flat land to allow the use of booms up to 36 m in width and where the capital outlay is justified by their usage (see Chapter 19). Animal drawn sprayers have also been used in some countries. Arable crop sprayers may now be fitted with air-assistance to improve the distribution of spray within a crop canopy. These sprayers are described in Chapter 10.

Tractor-mounted sprayers

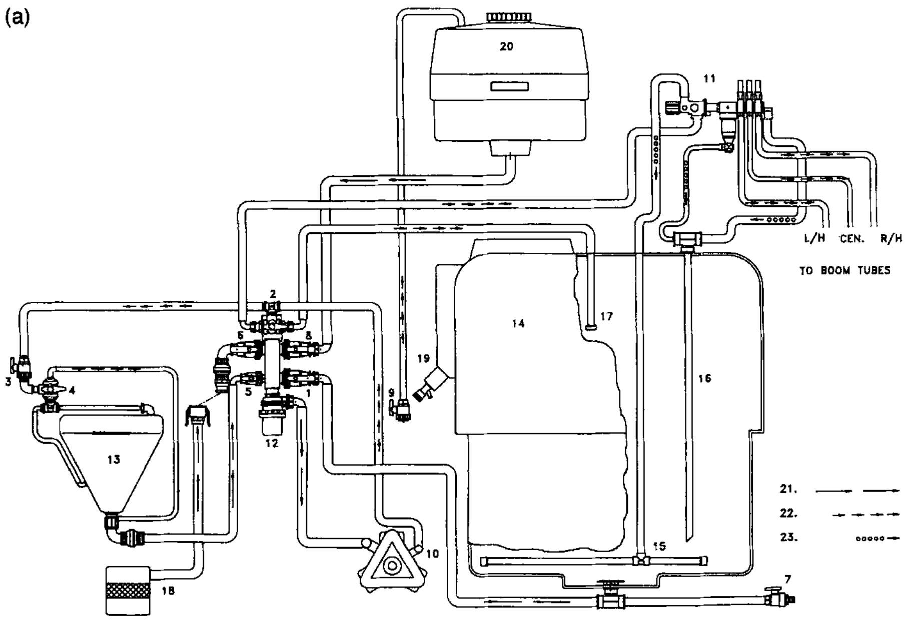
Tank design

A typical layout for a modern tractor-mounted sprayer is shown in Fig. 7.2. Most tractors have a standard three-point linkage on which the sprayer is mounted. The capacity of the tank is restricted by the maximum permitted weight specified for the tractor; half the sprayers in the UK have a tank of

Fig. 7.1 Various types of power-operated hydraulic sprayers (photos: Allman & Co.).

less than 750 litres capacity. Weights may be needed on the front end of the tractor, particularly the small tractors, to maintain stability. The farmer may prefer to use a smaller tank to reduce compaction of soil under the tractor paths, but if tank capacity is too low, frequent refilling may be required. The choice of spray tank size is also discussed in Chapter 19 in relation to other variables.

Most modern sprayers have tanks constructed with a corrosion-resistant material such as multilayer plastic. The tank should have a large opening (> 300 mm) so that the inside can be scrubbed out if necessary. A large opening



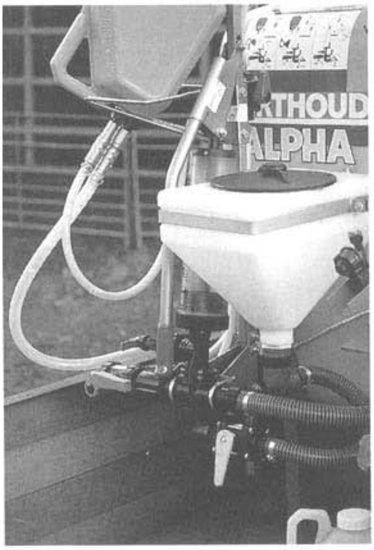
1. Suction valve
2. Change-over valve
3. Pressure valve
4. Pressure valve
5. Suction valve
6. Suction valve
7. Valve
8. Suction valve
9. Valve
10. Pump
11. Control assembly
12. Suction line filter

'V1' From tank to manifold
'V2' To contr./tank wash
'V3' Induction hopper main ON/OFF
'V4' Induction hopper Fill/can wash
'V5' Induction hopper Drain
'V6' Direct self-fill ON/OFF
'V7' Tank drain
'V8' Tank flush
'V9' Tank flush. Mains fill

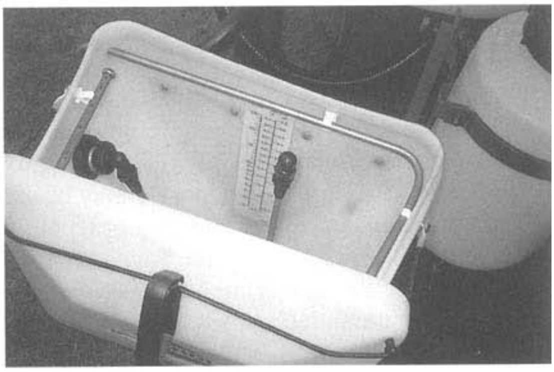
13. Induction hopper
14. Tank
15. Agitator
16. Dump pipe
17. Tank wash
18. Self-fill hose c/w strainer
19. Clean water tank
20. Flush tank (Optional extra)
21. Suction line
22. Pressure line
23. Return line

Fig. 7.2 (a) Layout of tractor-mounted sprayer (Allman & Co.). (b) Lower level induction bowl. (c) Nozzle to wash containers in induction bowl. (d) Locker for PPE. (e) and (f) Closed transfer systems.

(b)



(c)



(d)

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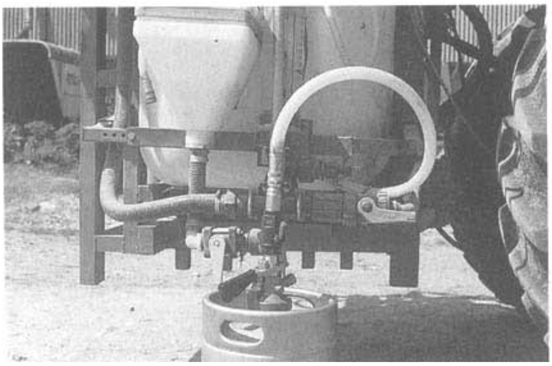


also facilitates filling the sprayer, but to improve safety for the operator, new sprayers are fitted with a self-fill system and in some cases a separate low-level mixing chamber. A large basket-type filter should fit into the opening, which is closed by a tight-fitting lid. The tank should have a drainage hole at its lowest point and a sight gauge visible to the tractor driver. The bottom of the tank should be fitted with a sparge-pipe agitator, that is a pipe with a line of holes along its length to give a series of jets of liquid to scour the tank bottom. Instead of a sparge pipe, a nozzle may be used to swirl the liquid over the tank bottom. Mechanical agitation is not recommended as, when the tank is nearly empty, the paddles may be only partly immersed and mix in air to cause foaming. A 200 litre drum has been used as a cheap tank on a sprayer, but this is not recommended, as rust is liable to occur quite rapidly inside metal drums.

Pumps

A number of different types of pump are used on tractor-mounted sprayers. Selection of the appropriate pump will depend on the total volume of liquid and pressure required for supplying all the nozzles and agitating liquid in the tank. The type of spray liquid will also influence the choice of pump, particularly the materials used in its construction. A comparison of pumps is given in Table 7.1.

Diaphragm pump

The basic part of the diaphragm pump is a chamber completely sealed at one end by a diaphragm (Fig. 7.3). The other end has an inlet and outlet valve. Liquid is drawn through the inlet valve by movement of the diaphragm enlarging the chamber, thus creating suction, and on the return of the diaphragm, it is forced out through the outlet valve. Some pumps have only one diaphragm, but usually two, three or more diaphragms are arranged radially around a rotating cam. This actuates the short movement of each diaphragm in turn to provide a more even flow of liquid instead of an intermittent flow or 'pulse' with an individual diaphragm. In any case a compression chamber, sometimes referred to as a surge tank, is required in the spray line if not incorporated in the pump to even out the pulses in pressure with each 'pulse' of the pump. These pumps are rather more complex as several inlet and outlet valves are required, but maintenance is minimal as there is less contact between the spray liquid and moving parts. Care must be taken to avoid using chemicals which may affect the diaphragms or valves. In general, diaphragm pumps are used to provide less than 10 bar pressure, but maximum pressures of 15–25 bar are attainable.

Piston pump

Liquid is positively displaced by a piston moving up and down a cylinder; thus

Table 7.1 Summary of types of pumps

	Diaphragm	Piston	Centrifugal	Turbine	Roller
Materials handled	Most; some chemicals may damage diaphragm	Any liquid	Any liquid	Most; some may be damaged by abrasives	Emulsion and non-abrasive materials
Relative cost	Medium/ high	High	Medium	Medium	Low
Durability	Long life	Long life	Long life	Long life	Pressure decreases with wear
Pressure ranges (bar)	0–60	0–70	0–5	0–4	0–20
Operating speeds (r.p.m.)	200–1200	600–1800	2000–4500	600–1200	300–1000
Flow rates (l/ min)	1–15	1–15	0–30	2–20	1–15
Advantages	Wear resistant Medium pressure	High pressures Wear resistant Handles all materials Self-priming	Handles all materials High volume Long life	Can run directly from 1000 r.p.m. p.t.o. High volume	Low cost Easy to service Operates at p.t.o. speeds Medium volume Easy to prime
Disadvantages	Low volume Needs compression chamber	High cost Needs compression chamber	Low pressure Not self-priming Requires high-speed drive	Low pressures Not self-priming Requires faster drive for 540 r.p.m. p.t.o. shafts	Short life if material is abrasive

the output is proportional to the speed of pumping and is virtually independent of pressure (Fig. 7.4). Piston pumps require a positive seal between the piston and cylinder and efficient valves to control the flow of liquid. To provide greater durability, the pump cylinder may have a ceramic sleeve. Owing to their high cost in relation to capacity, piston pumps are not used very much on tractor sprayers, but are particularly useful if high pressures up to 40 bar are required. A compression chamber is also required with these pumps. Piston pumps are less suitable for viscous liquids.

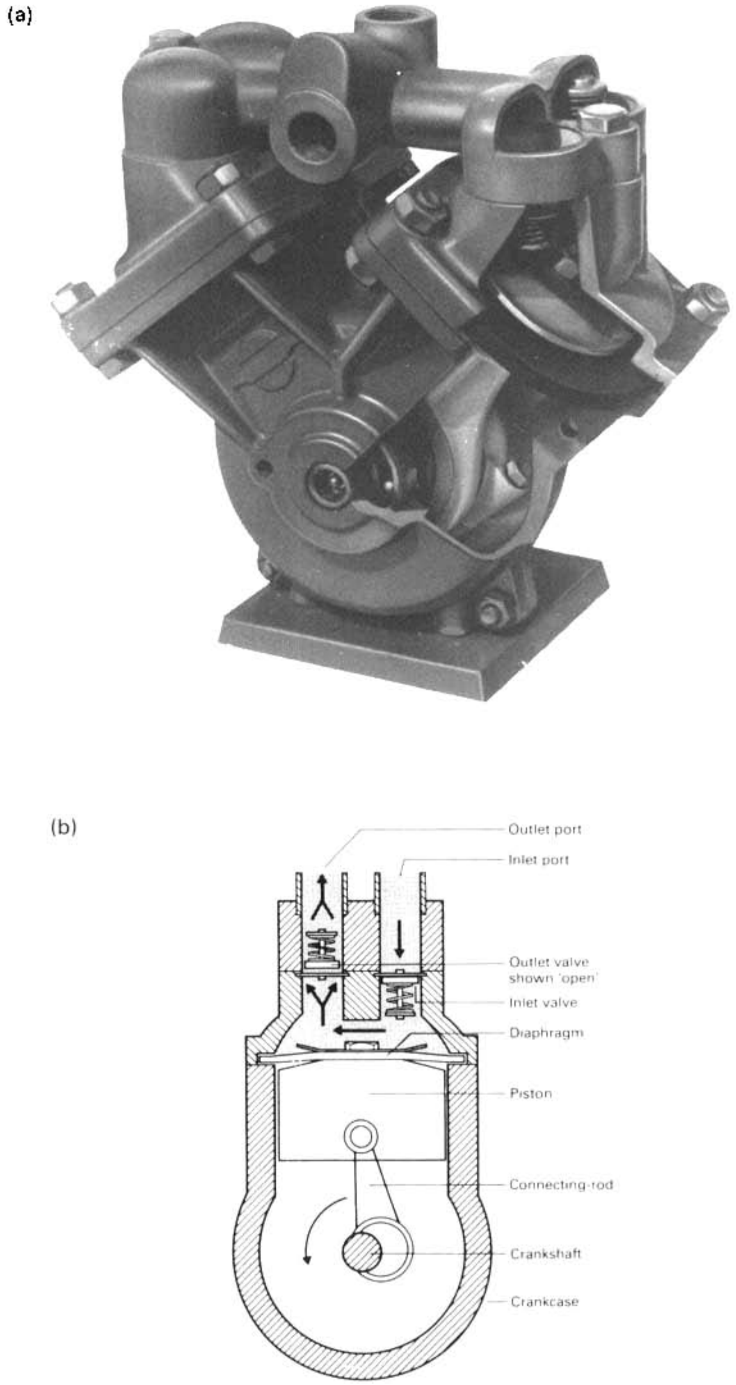


Fig. 7.3 (a) Diaphragm pump partly cut away to show diaphragm and valves (Hardi, UK). (b) Diagram to show construction.

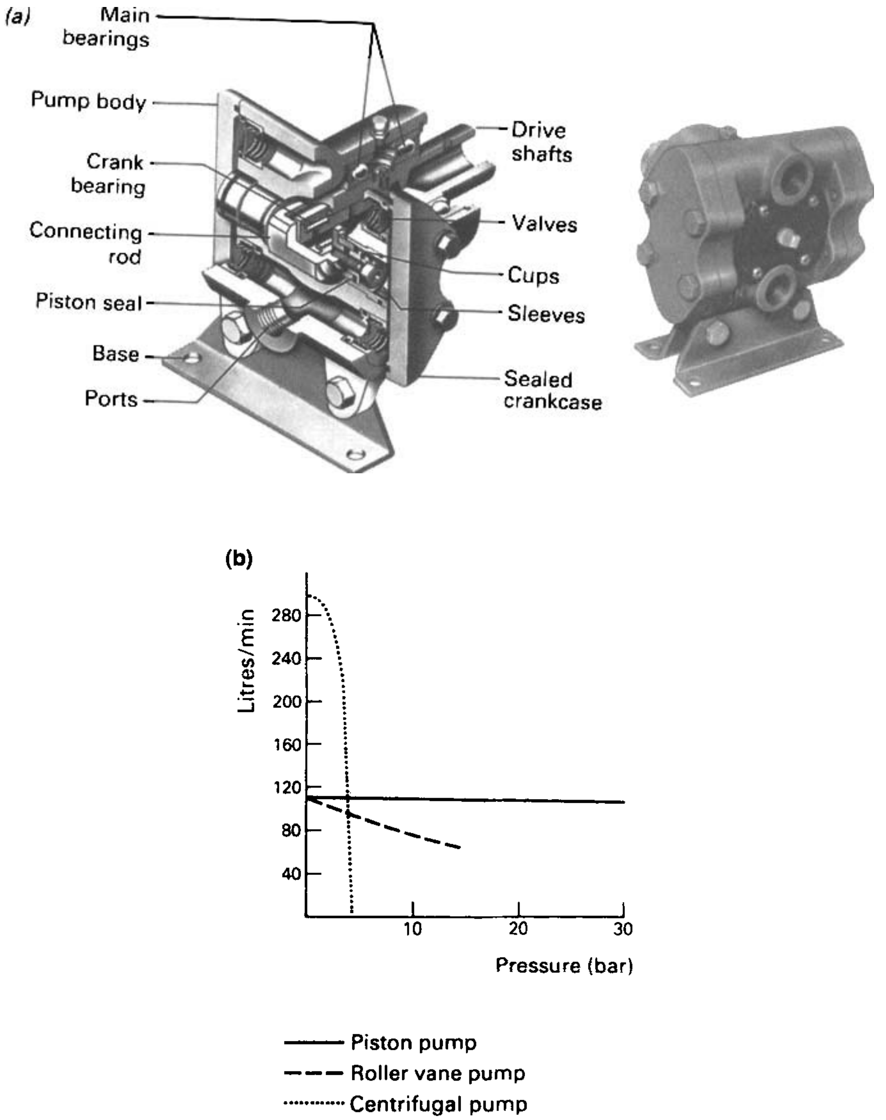


Fig. 7.4 (a) Piston pump cutaway and intact (photo: Delavan). (b) Performance of piston pump related to other types. Note: a compression chamber or surge tank must be placed with either a piston or diaphragm pump to even out pulses of pressure.

Centrifugal pump

An impeller with curved vanes is rotated at high speed inside a disc-shaped casing, and liquid drawn in at its centre is thrown centrifugally into a channel around the edge. This peripheral channel increases in volume to the outlet port on the circumference of the casing (Fig. 7.5). Centrifugal pumps are ideal for large volumes of liquid, up to 500 litres/min at low pressures. They can be used up to 5 bar, but the volume of liquid emitted by the pump decreases very rapidly when the pressure exceeds 2.5–3 bar. The pressure will increase slightly if the outlet is closed while the pump is running, and then slippage occurs

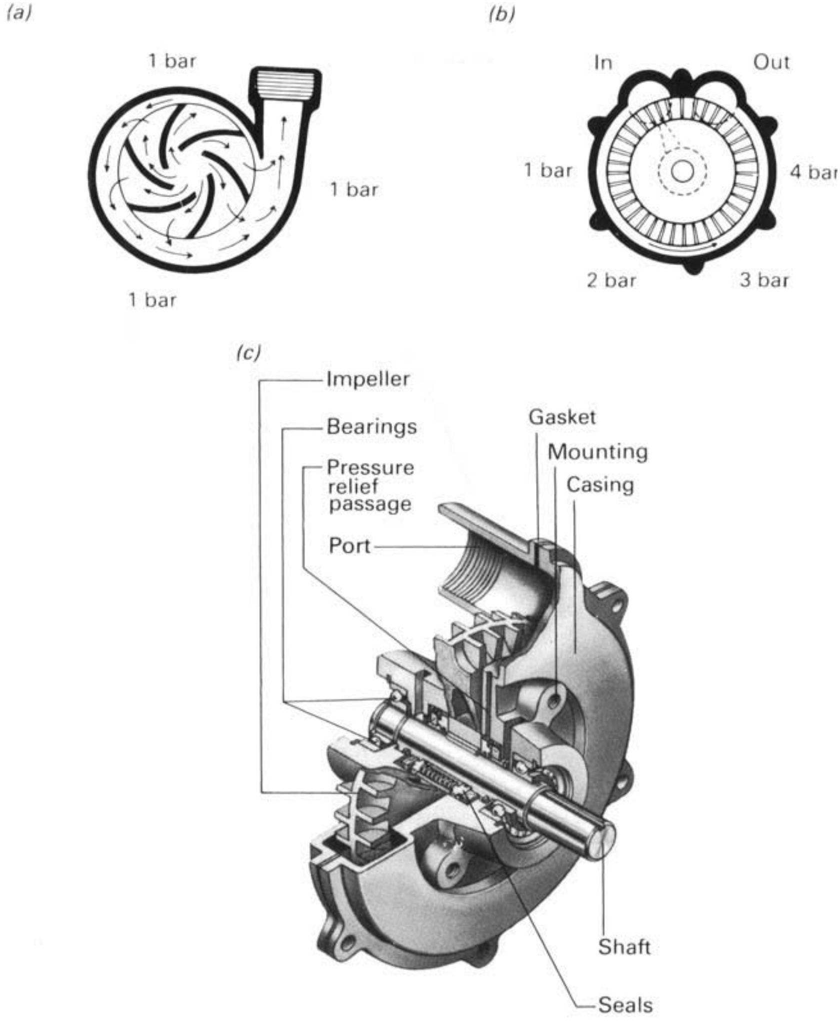


Fig. 7.5 (a) Centrifugal pump. (b) Turbine pump. (c) Cutaway to show construction of turbine pump (photo: Delavan).

without damage to the pump. Viscous liquids and suspensions of wettable powders and abrasive materials can be pumped. The seals on the shaft are liable to considerable wear as the pumps are operated at high speeds, but there is less wear on other parts as there are no close metal surface contacts. Instead of mounting a centrifugal pump directly on the p.t.o., a belt or pulley drive is required to obtain sufficient rotational speed of the pump. The pump may also be driven by a hydraulic motor from the tractor. Centrifugal pumps with a windmill drive are frequently used on aircraft spray gear. These pumps are not self-priming, and should be located below the level of liquid in the tank.

Pressure is increased in the turbine pump with a straight-bladed impeller in which liquid is circulated from vane to channel and back to the vane several times during its passage from the inlet to outlet port.

Gear pump

Gear pumps (Fig. 7.6) are seldom used, and have been superseded by either the roller-vane or diaphragm pumps. The gear pump consists of two elongated meshed gears, one of which is connected to the tractor. The gears revolve in opposite directions in a closely fitting casing, the liquid being carried between the casing and the teeth to be discharged as the teeth enmesh once more. Any damage or wear to the gears or the casing results in a loss in efficiency; therefore these pumps should not be used to spray wettable powders or where dirty water is used for spraying. A spring-loaded relief valve is usually incorporated in the pump to avoid damage caused by excess pressure. Outputs of 5–200 litres/min can be obtained with pressures up to 6 bar, although they are usually operated at lower pressures. These pumps were normally made in brass or stainless steel but engineering plastics have also been used.

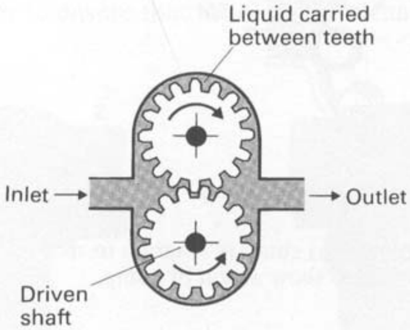


Fig. 7.6 Gear pump.

Roller-vane pump

This pump (Fig. 7.7) has an eccentric case in which a rotor with five to eight equally spaced slots revolves. A roller moves in and out of each slot radially and provides a seal against the wall of the case by centrifugal force. Liquid is

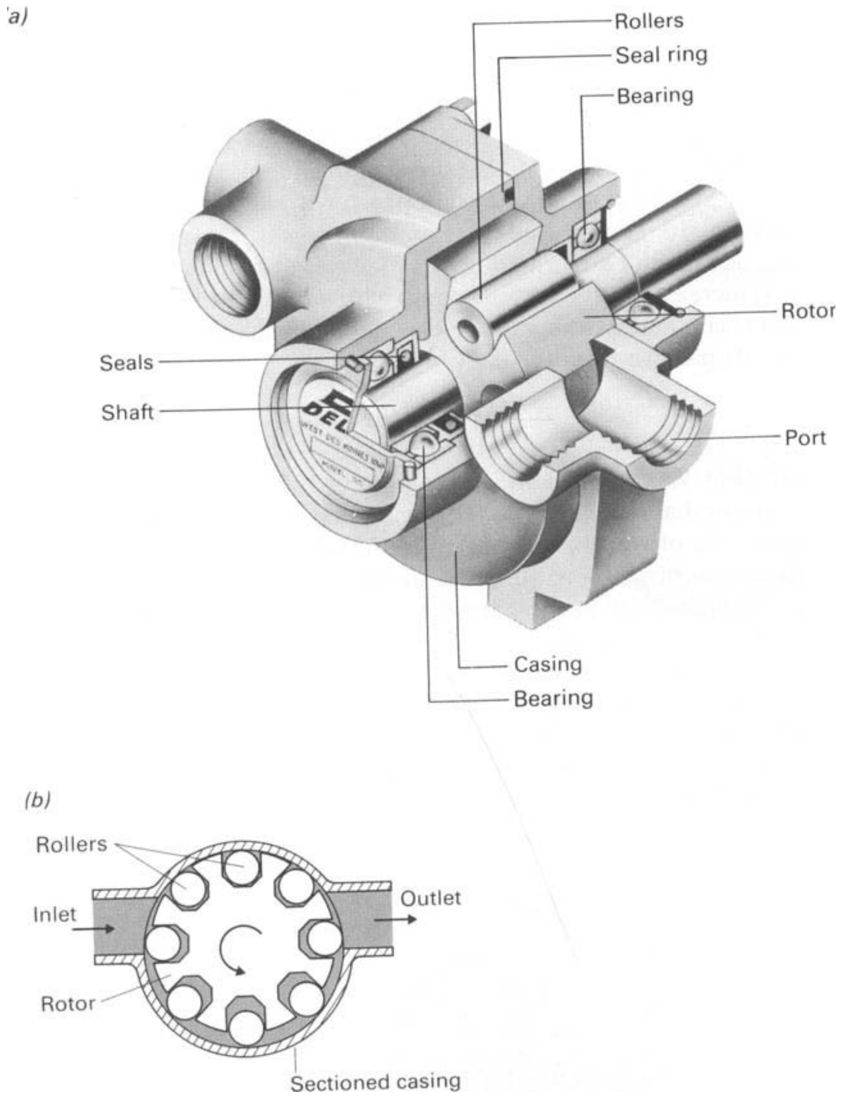


Fig. 7.7 Roller vane pump: (a) cutaway diagram to show construction (photo: Delavan); (b) diagram to show action of pump.

forced into the expanding space between the rotor by atmospheric pressure on the liquid in the tank as the rollers pass the inlet port on one side of the pump creating a low pressure area. As the space contracts again, liquid is forced through the outlet port. The pump is easily primed. Nylon or Teflon rollers are resistant to most pesticides, including wettable powder suspensions. Rubber rollers are recommended to pump water and wettable powders when the pressure does not exceed 7 bar. However, sand particles contaminating water supplies can abrade and damage the pump, so a filter between the spray tank and the pump inlet is essential to reduce the damage. The rollers can be replaced when necessary or the whole pump returned to the manufacturers for reconditioning. The case is usually made of cast iron or corrosion-resistant Ni-Resist, and has replaceable Viton, Teflon or leather, shaft seals. The pumps are usually designed to operate at p.t.o. speeds of 540–1000 r.p.m. with outputs from 20 to 140 litres/min, with pressures up to a maximum of 20 bar, although at higher pressures output and pump life are reduced. Output is approximately proportional to speed. The roller-vane pump is compact in relation to its capacity and is readily fitted to the p.t.o. and attached to a torque chain on the tractor. Before mounting, the pump shaft should be turned by hand, or with the aid of a wrench, to check that it turns easily in the proper direction.

Filtration

Careful filtration of the spray liquid is essential to prevent nozzle blockages during spraying. Apart from a filter in the tank inlet, a filter, or line strainer, must protect the pump on its input side (Fig. 7.2), and each individual nozzle, should have a filter. At the nozzle, the apertures of the filter mesh should be not more than half the size of the nozzle orifice. The line strainer should have a large area, ideally of the same mesh or slightly coarser than that used in the nozzle filter, to cope with the capacity of the pump. The line strainer should be positioned to collect debris on the outside of the mesh at the bottom of filter, so that blockage is unlikely to occur, even if debris has collected (Fig. 7.8). All filters should be regularly inspected and cleaned. Some manufacturers provide 'self clean' filters. With these it is possible to back-flush debris collected on the screen. While suitable for temporarily cleaning the filter to complete spraying in the field, it is better to ensure that the screen is cleaned each day.

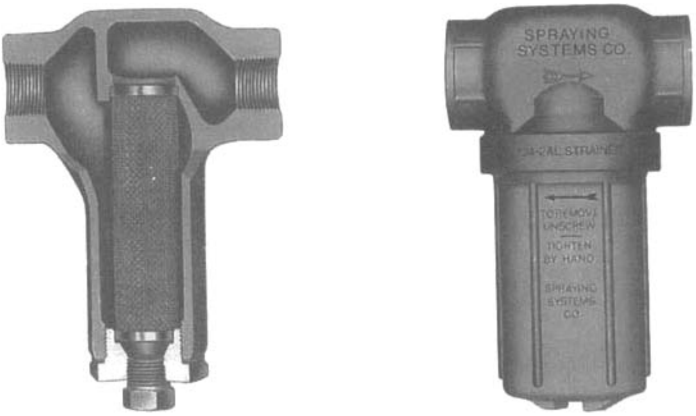


Fig. 7.8 Line strainer (photo: Spraying Systems Co.).

Pressure control

A pressure-regulating valve (PRV) (Fig. 7.9) controls flow of spray liquid from the pump to nozzles. This consists of a spring-loaded diaphragm or ball valve that can be set at a particular pressure. When this pressure is exceeded, the valve opens and the excess liquid allowed into a by-pass return to the spray tank; this causes hydraulic agitation of the spray liquid. The return flow should be through a suitable agitator at the bottom of the tank to ensure thorough circulation of the liquid. Some sprayers have a separate flow line to the agitator in addition to the by-pass line from the pressure-regulating valve. When the pressure gauge is mounted next to the valve, readings have to be checked against pressures measured at the nozzles, so that account is taken of any drop in pressure between the valve and the nozzles. The drop in pressure to the end of a boom depends on the capacity of the boom, output of the nozzles and input pressure. It is important that the bore of the boom is adequate for the nozzles being used. Ideally, the output and pressure of liquid from the pump is in excess of total requirements of the nozzles, so that hydraulic agitation in the spray tank is continuous and sufficient to keep wettable powders in suspen-

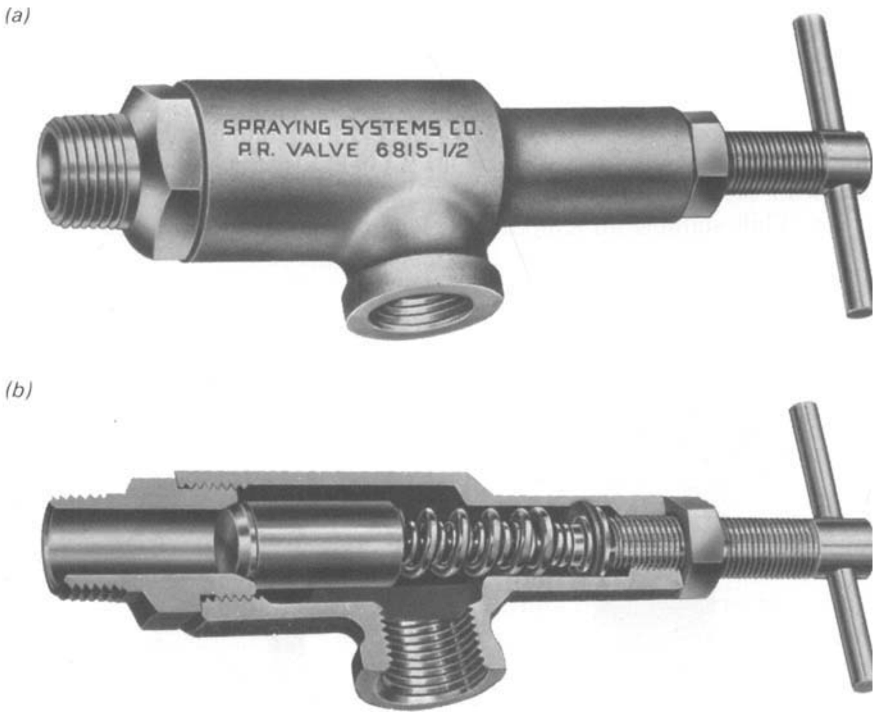


Fig. 7.9 (a) Pressure relief valve (photo: Spraying Systems Co.); (b) cutaway to show construction.

sion, even when spraying at maximum output. Unfortunately, pressure gauges do not remain reliable under field conditions and the gauge and sprayer calibration should be checked regularly. The life of a pressure gauge can be increased if a diaphragm (Fig. 7.10) protects it. Some are filled with glycerine to dampen vibration of the needle. A gauge should have a large dial to facilitate reading.

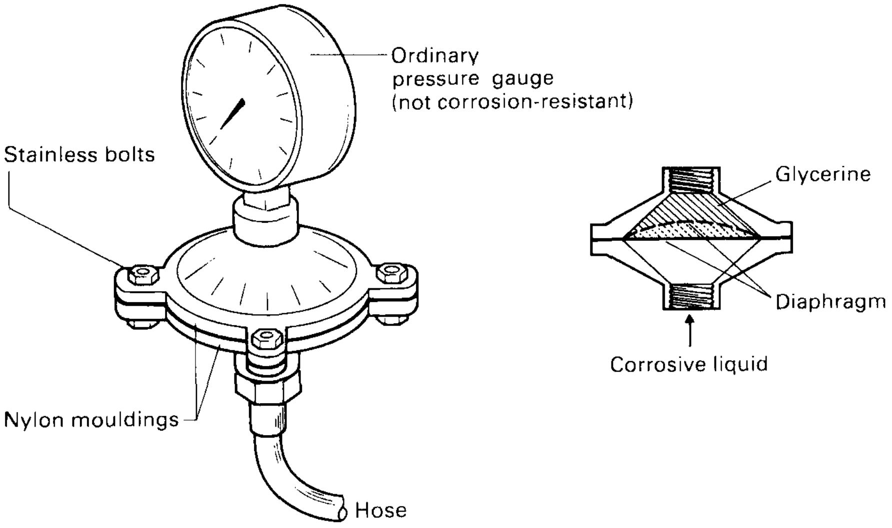


Fig. 7.10 Pressure gauge isolator.

Between the PRV and the nozzles, an on/off valve is positioned so that the tractor driver can easily operate it. Often there is a simple mechanical lever for the driver to operate, but for the totally enclosed safety cabs, electrically operated solenoid valves (Fig. 7.11) are required for remote control and to avoid pipes containing pesticides being in the cab. Closed cabs with charcoal-filtered air-intake units minimise exposure compared to half-open tractor cabs (Vercruysse *et al.*, 1999b). Some electronic devices are available to provide the tractor driver with a digital display of the area covered, output, speed and other variables (Allan, 1980). Such remote control devices are likely to be used more frequently due to safety regulations. When the spray boom is divided into three sections, left, right and central, the main valve is often a seven-way valve, so that individual sections, pairs or the whole boom can be operated. This is particularly useful when the edges of fields are being treated and part of the boom is not required. On some sprayers, liquid in the boom can be sucked back to the tank when the valve is closed. This may result in excess foaming and care must be taken to avoid damage to the pump if the sprayer is empty.

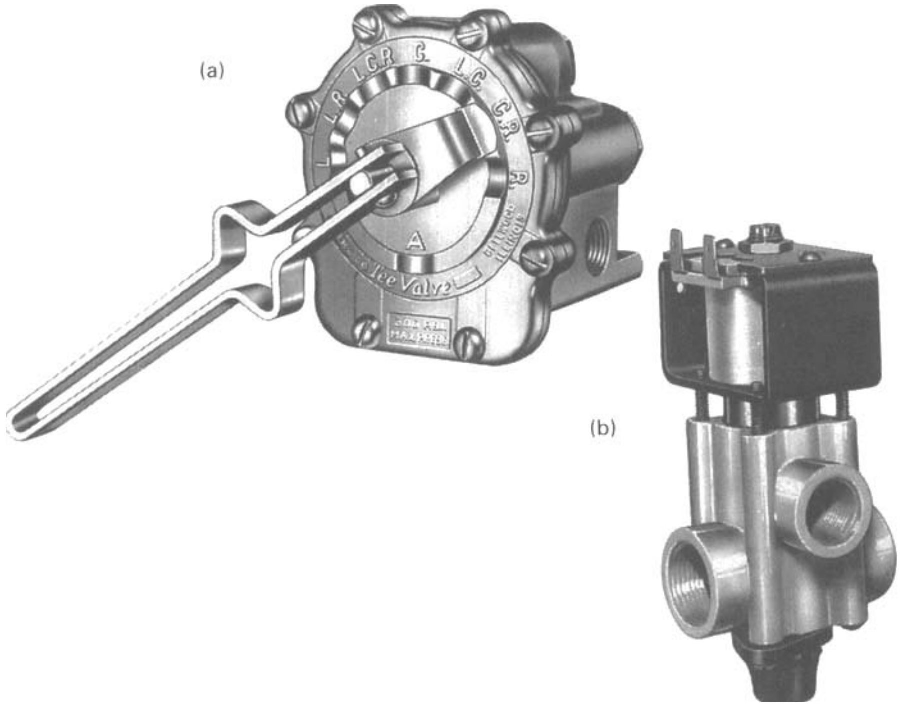


Fig. 7.11 (a) Seven-way tap for different boom sections. (b) Solenoid valve (photos: Spraying Systems Co.).

Spray booms

For most farmers the width of the boom is fixed. A suitable boom width for the fields can be calculated from

$$\text{Boom width} = \frac{\text{Area requiring treatment}}{\text{Time available} \times \text{Tractor speed}} = \frac{\text{m}^2}{\text{h} \times \text{m/h}}$$

Thus, if a farmer has a 100 ha field which needs treating in 3 days (6 h actual spraying per day) at a speed of 8 km/h, the minimum boom width required is 6.94 m (i.e. 7 m). Sprayer requirements should be based on completing the spray programme within 3 days in any one week to allow for rain, wind, equipment maintenance and other delays. On this basis, 1 m of boom is required for each 13.5 ha to be treated. Over the last two decades, farms in the UK have moved from boom widths of about 12 m to 18–24 m depending on the width of the seed drill and position of the tramlines, as this reduces the number of passes across fields. Variation in spray deposit is liable to increase with wide booms, due to greater movement of the end of the boom relative to the ground unless the land is very even. The pump output in litres/min is given by

$$\frac{\text{Swath (m)} \times \text{Application rate (litres/ha)} \times \text{Velocity (km/h)}}{600}$$

For example, with a 24 m boom travelling at 8 km/h, the pump capacity required to apply 200 litres/ha is 64 litres/min to allow for agitation. In practice, the cereal farmer also needs to choose a boom width related to the width of the seed-drill.

Boom design

Most spray booms are mounted at the rear of the spray tank, except for a few which are in front of the tractor to facilitate band applications of herbicides when the farmer needs to see the position of the nozzles in relation to the rows. The front boom position should not be used when spraying insecticides because the operator moves towards the spray. Booms are generally designed in three or more sections so that the outer sections can be folded for transport and storage. During spraying, the outer sections are often mounted so that they are moved out of the way by any obstruction which is hit. Manufacturers have used various methods to pivot and fix the boom sections for easy handling. Normally, the booms are unfolded by hand, but on some sprayers, positioning of the boom can be controlled through the hydraulic system without the operator leaving the tractor.

During field spraying, movements of the boom, including vertical bounce, horizontal whip or both, cause uneven distribution of pesticide, which is accentuated as booms increase in width. Due to the yawing, the boom may be stationary at times in relation to ground speed, so causing an overdose of pesticide. The rolling movement varies the height of nozzles relative to the crop, and thus the pattern of overlap is affected. Ideally, the boom should be as rigid as possible over its length and mounted centrally in such a way that as little as possible of the movement of the tractor is transmitted to the boom. Any breakaway mechanism should be strong and return the outer boom quickly and positively into its correct position. Booms constructed as stiff cantilevers have been shown to be better than other types (Nation, 1982). An inclined-link boom suspension was developed to allow articulation between the boom and sprayer in both rolling and yawing planes (Nation, 1985). Instead of a passive suspension, a boom can now be fitted with an active suspension in which a sensor detects the height of the boom relative to the crop and controls its position (Frost, 1984; Marchant, 1987; O'Sullivan, 1988; Frost and O'Sullivan, 1988; Marchant and Frost, 1989).

The effectiveness of shields fitted to spray booms has been investigated to assess whether drift can be reduced. Shielded booms did reduce off-target drift, but solid shields decreased on-swath uniformity in contrast to a perforated shield (Wolf *et al.*, 1993). A double-foil shield used with standard flat fan nozzles produced the best deposit and reduced drift by 59 per cent in wind tunnel tests (Ozkan *et al.*, 1997). By using a simple bluff plate attached to a boom driven at high speed (20–40 km/h) and applying low volume (11–15 litres/ha) sprays, oncoming air is deflected over the plate to create an area of stalled air where the nozzles are situated. Turbulence created assists downward movement of droplets into the crop canopy (Furness, 1991). Drag created by the plate requires a powerful tractor and requires more energy to maintain the high speeds, but in a new design the front is angled to deflect air over the top. Similarly Enfalt *et al.* (2000) used a plastic sheet mounted on a parallelogram frame to shield nozzles angled backwards behind the shield. Felber (1988) mounted a simple bar below the boom to open the cereal canopy and allow better penetration to the lower canopy for fungicide application.

Nozzles on spray boom

A wide range of hydraulic nozzles (see Chapter 5) can be used on a boom. Certain organisations have issued charts to guide farmers in the selection of nozzles (Powell *et al.*, 1999). Some farmers use twin-fluid nozzles that require the fitting of an air compressor and related pipes to deliver air to each nozzle (see also Chapter 10). The nozzle body may be screwed into openings along the boom, but often the boom incorporates special nozzle bodies clamped to the horizontal pipe (Fig. 7.12). Sometimes the liquid is carried to the nozzles in a plastic tube so that spacing between nozzles can be adjusted by sliding the nozzle body along the boom (vari-spacing). Choice of nozzle tip depends very much on the material being sprayed, the volume of liquid needed and the ultimate target, so that the output (litres/min), spray pattern quality and angle and droplet size are appropriate. Cone nozzles are preferred for application of insecticides and fungicides to foliage of broad-leaved crops, while fan nozzles are mostly used when treating wheat and similar cereal crops or the soil with any pesticide. To reduce drift, herbicides may be sprayed at low pressure,

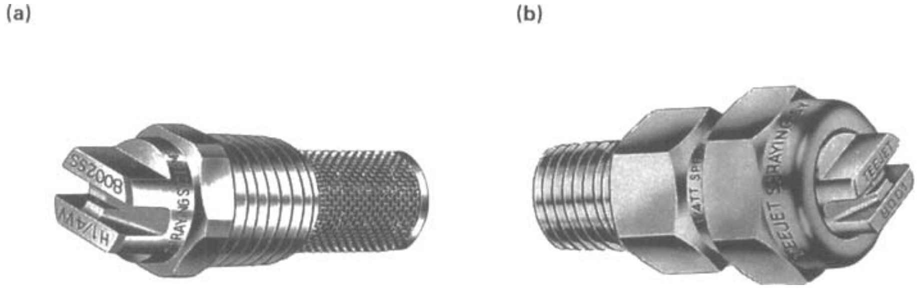
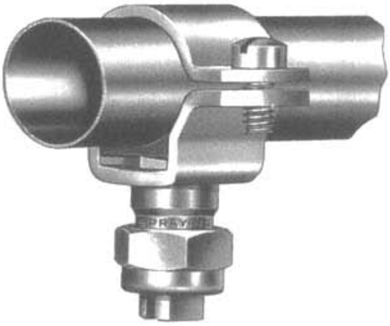


Fig. 7.12 Different systems of fitting nozzles to spray booms: (a) conventional nozzle body screws into boom; (b) nozzle tip screws directly into boom; (c) nozzle body clamps to pipe boom; (d) nozzle fixed to L-section boom with hose between nozzles; (e) vari-spacing; (f) bayonet fitting of nozzle tip; (g) double swivel nozzle on down pipe (photos: Spraying Systems Co.); (h) nozzle turret for rapid selection of different nozzles in the field (Lechler).
Note: Although metal nozzles are shown, many plastic nozzles are now used.

(c)



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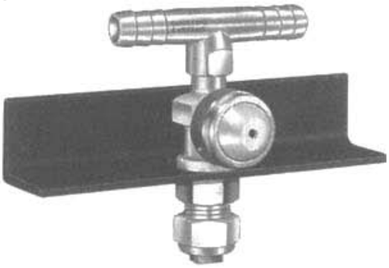

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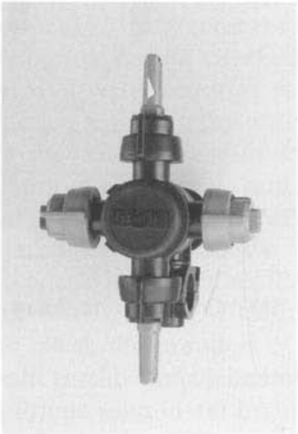

usually 1–2 bar. A check valve should be used with each nozzle to prevent dripping of liquid if the sprayer is stationary.

The throughput for each nozzle can be determined from the output of the pump and the number of nozzles on the boom, thus

$$\begin{array}{c}\text{Nozzle throughput}\\ \text{litres/min)}\end{array} = \frac{\text{pump output (litres/min)}}{\text{Number of nozzles}}$$

$$= \text{Pump output (litres/min)} \times \frac{\text{Nozzle spacing (m)}}{\text{Boom length (m)}}$$

For example, with a pump output of 18.6 litres/min on a 12 m boom with nozzles spaced at 0.5 m

$$\text{Nozzle throughput} = 18.0 \times \frac{0.5}{12} = 0.775 \text{ litres/min}$$

The spacing between nozzles along the boom is often fixed, and the height of the boom should be adjusted according to the type of nozzle being used. In particular, attention must be given to the spray angle and pattern, which are affected by pressure. The pattern from each nozzle has to be overlapped to achieve as uniform a distribution of spray as possible across the whole boom (Fig. 7.13); indeed some operators use a double overlap. If the boom is set too low, excessive overlap occurs and results in an uneven distribution. The 'peaks' and 'troughs' occur with both fan and hollow-cone nozzle, but are generally more pronounced with the latter. Uneven distribution is also obtained if the boom is set too high (Fig. 7.14 and Table 7.2).

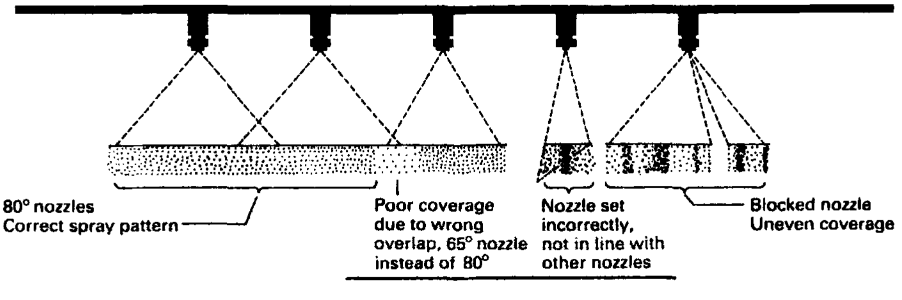

Fig. 7.13 Correct overlapping of the spray patterns is required across the boom.

Potential spray drift is increased with faster forward speeds, thus with 110° standard fan nozzles emitting 0.6 litres/min at 3 bar on a 12 m boom, drift at 5 m downwind was increased 51% when the tractor speed was increased from 4 to 8 km/h. This change in forward speed had a greater effect than increasing pressure up to 4 bar. This was because an increased pressure increased the downward velocity of droplets as well as producing smaller droplets (Miller and Smith, 1997). Nordby and Skuterud (1975) recommended that the boom should be about 40 cm high and the working pressure of fan nozzles kept below

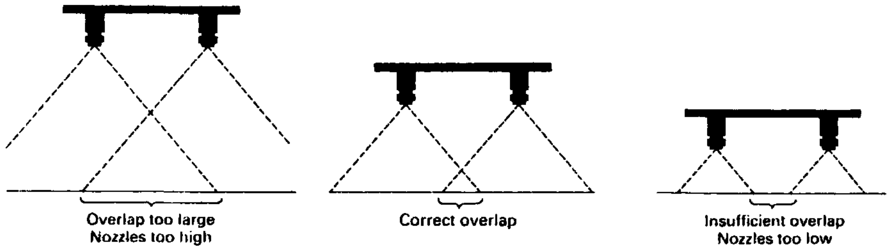

Fig. 7.14 Correct height above the crop is essential.

Table 7.2 Variation in boom height (cm) above crop or ground with different nozzle spacing along the boom and spray angles.

Nozzle angle	Nozzle spacing along boom (cm)		
(deg)	46	50	60
65	51	56	66
80	38	46	50
110	24	27	29

2.5 bar. Furthermore, they felt that herbicide sprays should be applied only when wind speeds are less than 3 m/s. Downwind drift is undoubtedly increased if the boom height is too high (Miller, 1988). Lower boom heights are possible if a fan spray is directed back at an angle instead of pointing vertically down on the crop (some nozzles are specially made to do this) or if wide-angle nozzles are used, but the wider the spray angle, the greater the risk of producing more very fine droplets. The distribution can be checked by spraying water onto a dry surface or placing strips of water-sensitive paper across the swath, or by adding a dye such as lissamine scarlet to the water, a record of the distribution being obtained by spraying across a band of white paper. If the spray pattern is uneven, the throughput of each nozzle must be checked (see p. 126). A computer model showed that for a boom set at the optimum height, the coefficient of variation increases continuously with increases in boom roll angle, due to the changes in nozzle height, rather than a change in the angle of the spray (Mawer and Miller, 1989). Electronic instruments to measure flow rate can be used to check the evenness of the output across a boom, but the actual output should be checked by collecting liquid in a calibrated container.

Most tractor-mounted booms have nozzles arranged in a horizontal line and directed downwards, but for spraying some crops to get underleaf cover, 'droplegs' are fitted so that nozzles can be directed sideways or upwards into the foliage (Fig. 7.15). When tailbooms were used on tractor equipment, they were pivoted on the horizontal boom and held by a strong spring. Also, the bottom section of the boom was mounted on a flexible coupling to avoid

Fig. 7.15 Tractor sprayer with vertical booms between row crop.

damage if the boom touched the ground. In front of the booms, a curved guard was needed to ease the passage of the boom through the crop. Movement through some crops is possible only if the sprayer is used regularly along the same rows and in the same direction.

Some chemicals are applied in a band, usually 18 cm wide, along the crop row to reduce the cost of chemical per hectare. Band spraying requires a higher standard of accuracy in the selection and positioning of the nozzles, which are often mounted on the seed-drill (Fig. 7.16). In one system in the USA where the nozzles are mounted so that they can be rotated up to 90° on a vertical axis, the user can control the bandwidth of a fan nozzle (Fig. 7.17). Guidance systems have been developed to ensure more precise positioning of the nozzle above small plants (Giles and Slaughter, 1997). A similar guidance system was developed to treat vegetation alongside roadways to avoid herbicide being applied to bare areas (Slaughter *et al.*, 1999).

Calibration of a tractor sprayer

The importance of careful calibration cannot be over-stressed. One method is to select the gear to give a p.t.o. speed of 540 r.p.m. and a forward speed which results in an acceptable level of boom movement. Next, a 100 m length is marked out and, with the tractor moving at the required speed as it passes the first mark, the length of time taken to cover the 100 m to the next marker is measured. The forward speed (km/h) = 360/measured time (s). The nozzle

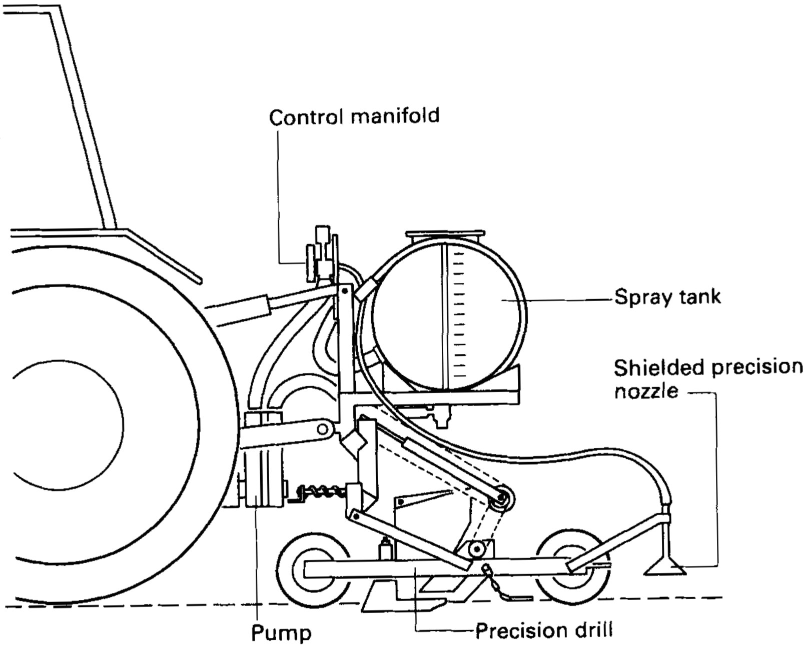

Fig. 7.16 Tractor-mounted band sprayer.

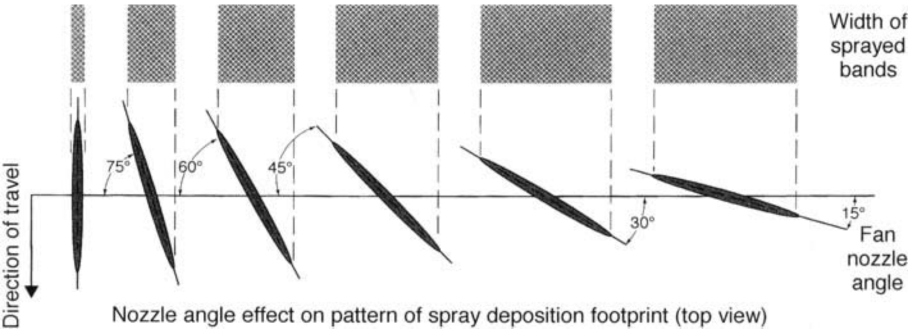

Fig. 7.17 Nozzle body with capstan to allow rotation up to 90° to vary swath width for band application.

spacing (m) is measured and the output required per nozzle is calculated as follows:

$$\text{Nozzle output (l/min)} = \frac{\text{Volume application rate (l/ha)} \times \text{Speed (km/h)} \times \text{Nozzle spacing (m)}}{600}$$

For example,

$$\text{Nozzle output} = \frac{200\,\text{l/ha} \times 6\,\text{km/h} \times 0.5\,\text{m}}{600}$$

$$= 1\,\text{l/min}$$

The nozzle is then selected from the information in the manufacturer's charts to emit the correct volume at the appropriate pressure and achieve the spray quality required. With the spray boom set up, the output of the nozzles is checked.

Another method, which can be used to check the calibration of the sprayer is to calculate the time, required to spray 1 hectare, thus:

$$\text{Time required (min)} = \frac{600}{\text{Swath (m)} \times \text{Speed (km/h)}}$$

Note the effective swath is the distance between each nozzle along the boom multiplied by the number of nozzles; for example, if 30 nozzles are spaced at 0.5 m intervals the swath is

$$30 \times 0.5\,\text{m} = 15\,\text{m}$$

The tractor speed can be checked by measuring the distance covered in metres when travelling for 36 seconds in a gear selected to give approximately the correct speed with a p.t.o. speed of 540 r.p.m. This distance divided by 10 gives the speed in kilometres per hour.

By knowing the time required to spray 1 hectare, the volume applied per hectare can be measured by filling the spray tank to a mark, operating the pump at the required pressure with the tractor stationary and the p.t.o. running at 540 r.p.m. for this period of time, and then carefully measuring the amount of water required to refill the sprayer to the mark. If the volume is within 5 per cent of that required, the pressure regulator can be adjusted slightly to raise or lower the pressure. However, adjustment of pressure must be avoided, because droplet size spectrum and spray angle are also affected and nozzle throughput is in proportion to the square root of the pressure; thus pressure needs to be doubled to increase throughput by 40 per cent. Alternatively, the speed of travel can be adjusted or, if necessary, different nozzles will be required. It is useful to keep different sets of nozzles to provide different spray qualities. Some sprayers have sets of nozzles in a rotating nozzle body to enable a change of nozzle tip to be made very easily. This may be particularly important when treating the edge of a field close to a watercourse when a LERAP rated nozzle – coarse spray – is required to avoid drift. If any adjustments are necessary, the sprayer calibration should be repeated.

The calibration can also be made by travelling over a known distance and measuring the volume (litres) applied. If the distance travelled is selected by dividing the boom width (m) into 1000, the volume measured multiplied by 10 is in litres per hectare. The pump pressure and speed of travel must be constant.

With a band spray, the application rate can be calibrated as described above, but as only a proportion of the area is actually sprayed; the rate per treated area will be higher in proportion to the ratio between the width of the treated plus untreated band and the treated band, thus:

$$\underset{(\mathrm{l/ha})}{\text{Volume applied to surface area}} \times \frac{\text{Treated band width} + \text{Untreated band width}}{\text{Treated band width}}$$

$$= \text{Volume applied to band (l/ha)}$$

For example, if 20 litres/ha is applied but confined to a band 20 cm wide along rows 100 cm apart, the volume applied to the band will be

$$20 \times \frac{100}{20} = 100 \text{ litres/ha}$$

Details of any calibration of the sprayer should be recorded for future reference (Table 7.3).

Table 7.3 Record of calibration

Tractor – make – registration

– tank capacity litres

Calibration	Tractor gear	Throttle setting (r.p.m.)	Ground speed (km/h)	Nozzle-tip size	Pressure (bar)	Output (l/h)	Area per load[a] (ha/tank)
1							
2							
3							

[a] Tank capacity (litres)/Output (litres/ha).

A sprayer should be cleaned and checked regularly. The main faults reported include worn nozzles, boom defects, damaged hoses, leaks and faulty pressure gauges. In many countries a sprayer must be officially examined at intervals of usually about 3 years to ensure that it is properly maintained. This mandatory examination by mobile inspection teams has led to an improvement in the general condition of sprayers, due to the financial consequences of a sprayer failing the test (Langenakens and Pieters, 1997). A stock of spare parts should be readily available. In particular, it is wise to keep spare nozzle-tips and take some to the field during spraying. If a nozzle is blocked, a replacement can be quickly fitted to avoid the need to clean a blocked nozzle in the field. The output of each nozzle should be checked periodically to ensure that it has not increased (see p. 129). The cost of a replacement nozzle is negligible in comparison with costs of the pesticides sprayed. The interval between checks will depend on the volume and type of liquid sprayed.

Swath matching

Matching the end of one swath with the next is not easy, especially in a closely spaced cereal crop. As the passage of the tractor wheels through the crop for fertilizer and pesticide application can reduce yield, especially at advanced stages of crop growth, farmers now leave gaps for the wheels of the tractor. These are referred to as 'tramlines' (Fig. 7.18a). Tillering, and more grains per ear on the plants adjacent to the gaps, almost compensates for the reduced plant population. With tramlines there is a small saving in seed, operations subsequent to drilling are quicker, and late applications, if needed, are more likely to be applied at the correct time.

The tramline system requires the width of the seed drill, fertilizer spreader and sprayer to match (Fig. 7.18b). Tramlines are established by blocking appropriate drill coulters at the required intervals across the field. The seed cut-off mechanism can be operated automatically on certain drills. Tractor tyre widths may also necessitate a slight displacement of the coulters on either side of the tramlines. Other systems are available, for example when the seed drill cannot be altered, a herbicide such as paraquat is sprayed behind the tractor wheels. The disadvantages of the technique are that it is more expensive, accurate marking is essential and greater care is needed to avoid spread of the herbicide to other areas. The headland operations and weed control must be carefully planned to ensure continuity of clean tramlines.

Fig. 7.18 (a) Field with tramlines (photo: J.W. Chafer).

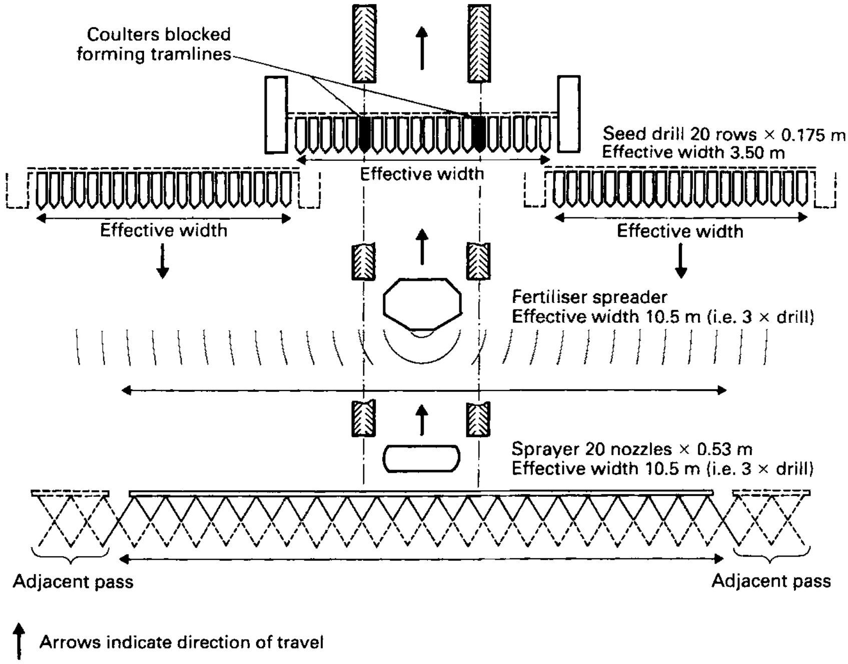

Fig. 7.18 (b) Diagram to show formation of tramlines by matching seed drill, fertilizer spreader and sprayer.

Increased attention to rabbit and hare control may be required, since these vertebrate pests may use tramlines as 'runs' into the fields. It is well worth spending some time measuring out each swath and having fixed marks to indicate the centre of each swath, even on row crops. Damage to bushy plants, like cotton, caused by the passage of the tractor is less than expected owing to plant compensation. Even when a tractor with a clearance of only 48 cm at the front axle was driven over two rows of cotton, it was more profitable than growing an alternative low crop, such as groundnuts, along the 'pathways' (Tunstall *et al.*, 1965).

The tramline system is now so widely used that alternative methods, such as the foam marker at the end of a boom, are seldom used. Often the crop is sown right up to the edge of the field and no headland is available for turning. When the turn is made inside the crop, the crop will be overdosed if spray is applied during the turns. It is preferable to spray two swath widths around the field, and then treat the remainder of the field by spraying swaths parallel to the longest side of the field. The p.t.o. is kept running during the turn to keep the spray liquid agitated, but the valve to the boom is closed throughout the turn (Fig. 7.19). However, some farmers now have an untreated headland, which is managed separately to conserve wildlife in the hedgerows.

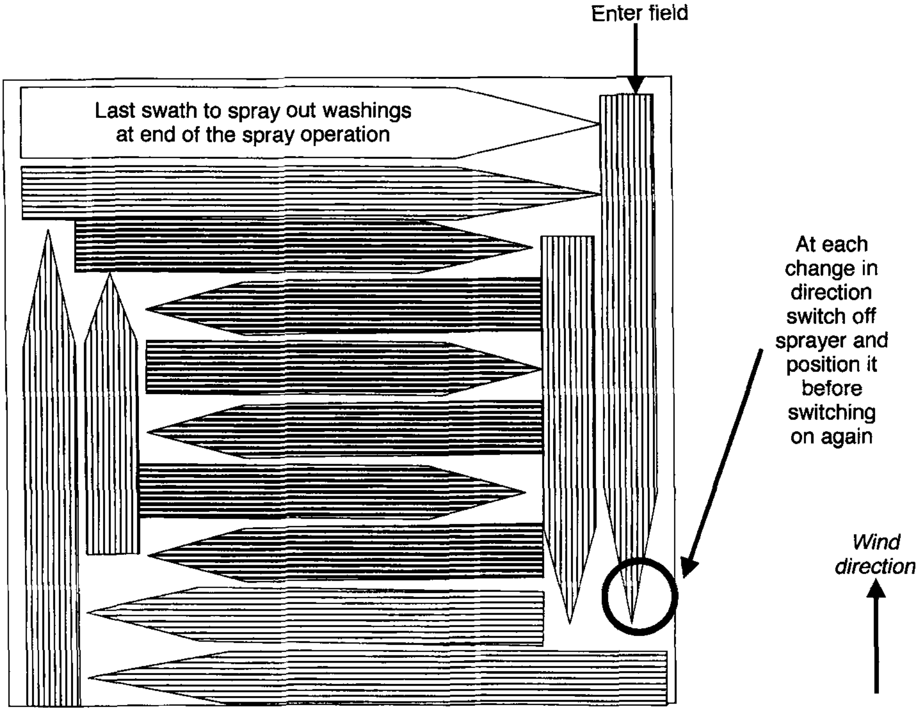

Fig. 7.19 Sequence of spraying a field. Never spray while doing a turn.

Refilling the sprayer

If the spray tank is not fitted with a sight gauge, a flickering of the pressure-gauge needle indicates that the sprayer is empty. The p.t.o should be disengaged immediately to avoid the pump running while 'dry'. Most operators prefer to empty the tank before refilling to avoid errors in calculating and measuring the amount of chemical for a different volume of liquid. Nevertheless, if the sprayer empties while in the middle or far side of a field, time is wasted in returning to the refilling point, and a smaller quantity may be required for the last load to avoid having any spray left over. If possible, the farmer should have detailed measurements of his field, so that with accurate calibration the appropriate amounts of chemical can be calculated beforehand for each load, thus reducing the time for ferrying to refill the sprayer.

To increase safety to the operator, the trend is to use the sprayer pump to fill the tank partially with water and then transfer and mix a measured quantity of pesticide using a closed-transfer system to reduce direct contact with the chemical (Brazelton and Akesson, 1987). Such systems include the use of a suction probe to use the sprayer pump to draw chemical from its container (Fig. 7.2). In Europe, an industry standard requires a closed coupling without any spillage, using equipment such as the MicroMatic. Most sprayers now have an induction bowl (Fig. 7.20) which is used especially with particulate formulations to provide mixing before the chemical is drawn into the sprayer tank (Frost and Miller, 1988). An International Standard for induction bowls is in preparation. This equipment is fitted with a system of using clean water to rinse containers to reduce residues and thus eliminate the hazards associated with disposal of contaminated containers. In one test 69 per cent of the participants were able to clean a 5 litre container so that it had less than 0.5 ml of pesticide residue after 20 s washing, and thus below the upper limit defined by the standard BS 6356 (Cooper and Taylor, 1998).

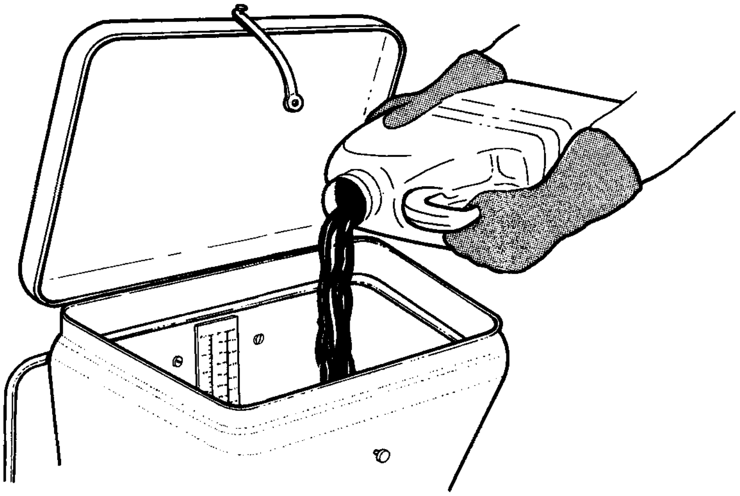

Fig. 7.20 Low-level induction bowl.

The chamber must be fitted with a system to rinse the container and in some the empty container can then be crushed to prevent re-use.

Alternatively, the farmer may have a separate water tank or mixing facility with its own pump to refill the sprayer. Great care must be taken to avoid contamination of the water source.

Metered spraying

Uniform application with the equipment described so far depends on a constant tractor speed and constant pressure. Forward speed may vary, so systems are needed to regulate the flow of liquid to the nozzles. A variation in speed from 0 to 80 km/h must be considered when herbicides are applied to railway tracks (Amsden, 1970). Some systems incorporate a metering pump which is linked to the p.t.o. or sprayer wheel, and a proportion of spray may or may not be returned to the tank. Pump output must be proportional to the forward speed, so a diaphragm or piston positive displacement pump is needed; gear or roller-vane pumps are unsuitable. When the pump – usually a piston pump with an adjustable stroke – is driven by the sprayer wheel, a second p.t.o. pump is needed for agitation and refilling the tank (Fig. 7.21). The main disadvantage is that the power required to drive the metering pump is high, 10 hp being needed to supply 500 litres/ha through a 12 m boom. This can be overcome by using the ground-wheel pump at low pressure and a separate pto pump to boost pressure to the nozzles. These systems are relatively simple to operate, but droplet size is also affected when flow rate is adjusted by pressure. The operator should try to keep within ± 25% of the selected speed so that the pressure is not greatly affected. Other systems include a centrifugal regulator linked to the sprayer wheel and metering pumps or valves operated electronically by the forward speed of the sprayer (Fig. 7.22).

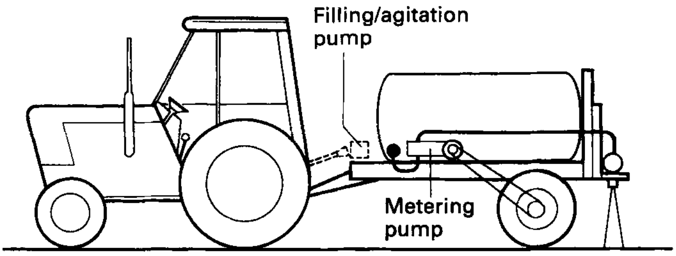

Fig. 7.21 Metering pump system.

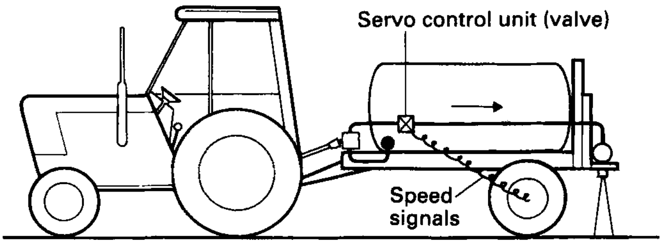

Fig. 7.22 Output controlled by electronic sensing of forward speed.

The more complex electronic systems are expensive, and their use is limited unless specialized maintenance facilities are available. All systems linked to the rotation of the p.t.o. or wheel may be affected by wheel slip causing underdosing or overdosing, so the metering device must be operated by a trailed wheel rather than a driving wheel (Amsden, 1970). The spray is already mixed in the sprayer tank with these automatic regulating systems. Ultimately, the chemical and diluent may be kept in separate tanks (Fig. 7.23) and using an in-line mixing system with the concentration of spray affected by forward speed (Hughes and Frost, 1985). Unused chemical can then be readily returned to the store. Frost (1990) has described a novel metering system in

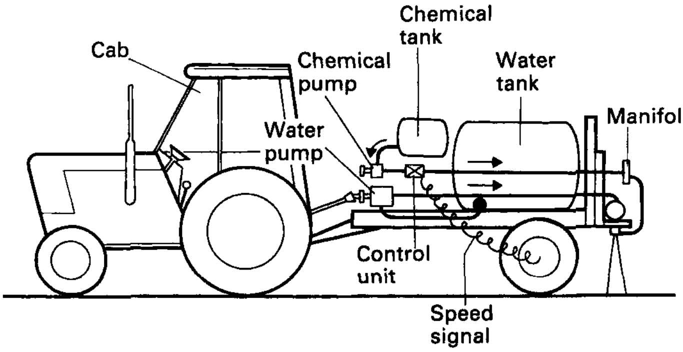

Fig. 7.23 Servo-operated system with separate chemical and diluent tanks and pumps.

which the flow of water is used to control the flow rate of the chemical, making the system independent of the characteristics of the chemical.

In another closed system, a piston pump with a ceramic piston to withstand the effects of the pesticide concentrate is used to meter the chemical into a mixing chamber. An electric stepper motor, controlled from the tractor cab, is used to adjust the length of pump stroke and thus the input of chemical into the water that is pumped separately into a mixing chamber and thence to the nozzles (Landers, 1988). Humphries and West (1984) describe a similar system that uses compressed air to force the pesticide to the mixing chamber. Zhu *et al.* (1998) describe how the lag time and uniformity of mixing can be assessed when an in-line injection system is operated.

Regardless of which system is used, the sprayer must be properly calibrated, and worn parts, especially nozzles, replaced regularly.

Precision (patch) spraying

Instead of treating the whole field, systems are being developed in precision agriculture to treat specific areas within fields according to the pests that are present. At present, patch spraying is mostly with reference to weeds, the type and position of which can be determined by walking the field and the locations recorded in a computer linked with geographical positioning systems (GPS) data (Rew *et al.*, 1997). The tractor can then be programmed to spray the patches. Paice *et al.* (1995) used a sprayer with an injection system, but an alternative system with a twin-boom and individual nozzles controlled by solenoid valves has been used commercially (Miller *et al.*, 1997). Womac and Bui (1999) have patented a device that will facilitate application at a variable flow rate and avoid the use of electrically complex equipment. Giles *et al.* (1996) have controlled the flow through nozzles using a pulsed solenoid independently of pressure, while controlling droplet size by adjusting the pressure of the spray liquid (see p. 123).

Portable-line sprayers

A flexible boom or hose can be used when a horizontal boom on a tractor cannot be used in orchards or forests, or because the land is undulating. Sufficient labour is needed to carry the hose. Various types of portable line have been used. In cotton fields, operators spaced at 4 m intervals carry an interconnecting hose on a short mast, supported in a waist strap. The interconnecting hose is liable to stretch unless strengthened by Terylene or a similar fibre in the hose wall. The portable line is connected to a spray tank and pump, mounted on a trailer driven or pushed along pathways across the field. The main difficulties with the system are the need for a pressure regulator at each operator to compensate for the pressure drop along the line, and the need for each operator to walk at the same speed as the tractor (sometimes difficult if an operator meets an obstacle or a snake!). With a line of spray operators, care must be taken to avoid contaminating each other with spray droplets drifting downwind.

Alternatively, a hose on a reel is paid out from a stationary pump as the operators move down the field and is wound in on their return. This method has been used in small orchards, as well as for cotton. These systems are generally no more expensive than using teams with knapsack sprayers, but require sufficient supervision to co-ordinate the operators and ensure that they do not get contaminated by the spray.

Incorporating herbicides

Some volatile herbicides, such as trifluralin and dinitramine, must be incorporated into the soil to prevent loss by volatilisation or photo-decomposition by sunlight. Incorporation also reduces the rainfall requirement and places the chemical in close contact with the weed seeds or roots for best control. The implements used for incorporation will vary with different herbicides, depending on the distribution of chemical required. Power-driven devices are required to incorporate herbicides evenly to a precise depth. Walker *et al.* (1976) reported that a single pass with a rotovator gave an even distribution of trifluralin in the top 5 cm of soil, i.e. its working depth. Incorporation to half its working depth was obtained by cross-cultivations with a rotary power harrow, reciprocating harrow, spring-tined harrow and disc cultivator. Single passes of these implements, and even cross-cultivation with a drag harrow, left much of the herbicide close to the soil surface.

Special booms for tree spraying

High-volume application (100 litres/tree) has been used to protect citrus trees. These sprays are applied with a vertical boom, which is mounted on the rear of a tractor travelling at 2–2.4 km/h. Narrow-cone nozzles (16°) with 2.4–3.5 mm orifices are placed at intervals of 30–40 cm, from 45 cm above the ground to no lower than the top of the average tree height. A high-capacity pump is needed to deliver up to 500 litres/min at pressures exceeding 30 bar. The nozzles are oscillated in a continuous cyclic rotation pattern once every 0.5–0.6 m of forward travel. The high pressures and volume with this system were considered essential to penetrate the peripheral 'shell' of foliage and achieve up to 88 per cent coverage, including the upper central parts of the trees (Carmen, 1975). However, Cunningham and Harden (1998, 1999) have pointed out that retention of spray on leaf surfaces, as a percentage of the spray applied, increases as the total volume applied decreased.

To treat small trees, it is possible to mount the boom within a tractor-mounted shield to reduce the effect of wind on spray dispersal (Cooke *et al.*, 1977). With the need to reduce spray drift in orchards there is likely to be an increase in the use of 'tunnel' sprayers (Fig. 10.16, p. 235).

High-volume fungicide sprays (800 litres/ha) to control coffee berry disease in East Africa have been applied with twin horizontal overhead booms covering eight rows (2.7 m apart) on a single pass (Pereira and Mapother, 1972). Deposits were predominantly on upper surfaces and decreased from the top to lower parts of the coffee, so that effective control of the disease depended on redistribution of the fungicide. Overhead spraying is less effective against coffee leaf rust because these spores germinate on the undersurface of leaves. Pereira (1972) has also described an inverted 'hockey-stick' boom at the rear of a tractor-mounted sprayer operated at 7 bar for both overhead and lateral spray application of coffee trees. Variable-cone nozzles, 250 mm apart, on the vertical section of boom were angled to spray up through the branches to improve coverage on the berries. Small fruit trees can be sprayed with an overhead boom.

Some experiments have been made with a crossflow fan driven by a hydraulic motor to provide an air flow to improve penetration of a tree canopy. The main advantage of the system is that a fan unit can be mounted on a hydraulically manoeuvred boom so that the nozzles are placed relatively close to the foliage (see p. 234).

Animal-drawn sprayers

Animal-drawn sprayers have been used where farmers have draught animals such as oxen. The tank, boom and pump are usually mounted on a suitable wheeled frame. A high-clearance frame is needed for some crops (Fig. 7.24). These sprayers can be operated even when conditions are too wet to allow the passage of a tractor, and the animals do not damage the crop. The pump can be driven by a small engine or by means of a chain drive from one of the wheels on the frame. When the latter is used, the pump has to be operated for a few metres to build up sufficient pressure at the nozzles before spraying starts. If wheel slip occurs, spray pressure will decrease.

Fig. 7.24 Animal-drawn sprayer with engine-driven pump.