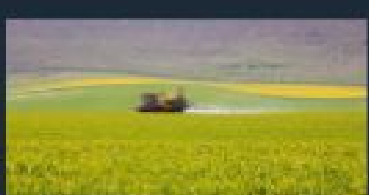
PESTICIDE APPLICATION METHODS

G. A. Matthews, Roy Bateman and Paul Miller

FOURTH EDITION



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Contents

Pesticide Application Methods

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Preface to fourth edition

Since the start of the new millennium, the public debate about genetically modified crops and demands for organic food have continued, as the global human population has now exceeded 7 billion (Bloom, 2011). ‘Organic’ food is usually more expensive to buy, but a vocal proportion of the population continue to prefer it as they perceive that residues of commercially manufactured pesticides in food are harmful. Where residues do occur, they are well below the maximum residue level (MRL), the limit set by the regulatory authorities that could occur with good agricultural practice. This contrasts with the possibility of more natural pesticides in crops left unprotected as these plants produce chemicals naturally (i.e. natural pesticides) to provide some protection against pests (Mattsson, 2007; Shorrocks, 2013). Furthermore, research in the UK by the Food Standards Agency and in the USA (Smith-Spangler et al., 2012) has shown that organic food is not more nutritious than conventionally grown farm produce. Over the last six decades with widespread pesticide use, food quality has been vastly improved and life expectancy has increased from an average of 48 to 68 years. At the same time, considerable attention has been given to environmental protection, especially to minimise pesticides polluting water, with emphasis on minimising spray drift from treated areas.

The world’s human population continues to increase with greater demands for food of high quality so there can be no return to growing crops without artificial fertilisers and some pesticide use. Genetically modified crops can provide a means of improving the quality of some crops by enhancing vitamin content or disease resistance. Globally, the two types of GM crops most widely used initially have been those expressing the *Bacillus thuringiensis* (Bt) toxin gene to check predominantly lepidopterous pests and those with resistance to the herbicide glyphosate. While adoption of Bt crops has generally reduced the number of pesticide applications, they still require spray treatments to control other types of pests, notably sucking pests such as aphids. Some pests are becoming resistant to the Bt toxin, indicating the requirement for 'refuge crops' to minimise resistance selection, but these have not always been adopted sufficiently to minimise these problems, associated with GM technology.

The herbicide-tolerant crops, such as 'Roundup Ready' crops, have depended on using one particular herbicide, which over time has led to serious weed problems, where herbicide-resistant weeds occur. This trend will continue with crops tolerant of other herbicides, stimulating research on herbicides with different modes of action. Thus one approach has been to develop crops tolerant of an old herbicide, 2,4-D (Green, 2012), which has caused concerns, as spray drift of this herbicide had adversely affected sensitive crops. However, a new formulation of 2,4-D and spray technology is being promoted to avoid this being repeated.

Biological and cultural controls are undoubtedly of great importance, but neither can respond rapidly to sudden outbreaks of pests, so pesticide use must form a key component of integrated crop management. Unfortunately, in many parts of the world the lack of infrastructure and trained personnel has resulted in misuse of pesticides. The challenge now is to spread the knowledge on safe use and correct application of pesticides beyond its present frontiers so that higher yields of crops can be obtained in the developing countries. Pesticides are only one of the tools and can only protect crops with a high yield potential to justify the expense of their use. We know more about more precise application with less pesticide lost in the environment, but more research is needed so that new technologies can be incorporated to minimise pesticide use and improve the timing of applications. Since the last edition of this book, development of hydraulic nozzles has provided droplet spectra less prone to drift beyond field boundaries, but care is needed to maintain biological efficacy within fields.

In Europe, new legislation (EC Regulation 1107/2009) replaced the earlier Directive 91/414/EEC and came into force in June 2011. EU countries must comply as it is a Regulation and not a Directive. In general, the aim has been to minimise risks of environmental pollution based on data obtained from manufacturers and to exclude the most hazardous compounds. It has also required greater safety in pesticide packaging with more emphasis on recycling of cleaned pesticide containers and has established rules to maintain equipment and minimise pollution. An amendment to the machinery, Directive 2006/42/EC, enables standards to be set for new pesticide application equipment being marketed.

This legislation has led to a significant reduction in pesticides that can be marketed, especially in Europe, but it also affects countries exporting crops to Europe as these must also comply with regulations on maximum residue levels (MRL). In one example, the pre-emergence herbicide simazine was submitted by manufacturers for inclusion in Annex 1 which lists all pesticides approved for use within Europe, but the Committee did not accept the calculations of the environmental concentrations in groundwater and considered that concentrations of simazine or its breakdown products would exceed 0.1 µg/L in groundwater. Simazine was therefore not included in Annex 1. One concern about the reduction of pesticides is that it is likely to limit the choice of products needed to maintain resistance management strategies.

Similar changes in the USA have resulted in the Clean Water Act requiring a National Pollutant Discharge Elimination System (NPDES) Permit when applications are made to control aquatic weeds, flying insects above water, for example aerial mosquito control programmes, and pests on plants near water, unless there is no point discharge of pesticide into the water. Thus general pesticide applications on farms do not need a NPDES permit. Legislation thus presents a distinct challenge to improve the precision of pesticide application, both in terms of placement and when an application is needed to minimise the amount of pesticide used in the environment..

A new Directive, 2009/128/EC, aims to achieve greater harmonisation on pesticide regulation throughout the EU and in effect bring standards up to levels similar to those which already apply in the UK. The Directive also requires Member States to develop national action plans to reduce further the risks associated with the use of pesticides and promote the use of low-input systems.

Funding for pesticide application, a multidisciplinary subject, has declined as research on genomics has expanded to develop new varieties of crops. Expansion of biopesticide use has been limited as insufficient attention has been given to the careful integration of formulation and application technology research to ensure that what is effective under laboratory conditions is also successful in the field. With major agrochemical companies now becoming more closely involved with biotechnology, no doubt use of biopesticides will increase.

In this edition, with the assistance of co-authors, a new chapter discusses the drift of spray beyond the treated areas and ways of mitigating drift. All the chapters have been revised to reflect changes that have occurred as a result of new developments and legislation. The aim has been to provide a text to assist with training and improve the safety and efficiency of application.

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Note

Since this book was submitted for publication, the European Union has announced a two-year moratorium from December 2013 on the use of neonicotinoid insecticides as seed treatments on bee-attractive crops, excluding those non-attractive to bees and winter cereals (see chapter 13, where seed treatment is described). Although insecticides have been blamed for the decline in bees (referred to as Colony collapse disorder), other factors need to be considered. Bees have been seriously affected by a mite *Varroa destructor* and viruses transmitted by the mites. Bees have also been affected from a loss of biodiversity in farming areas, although conservation programmes since the 1990s have encouraged areas to be sown with wild flowers.

Acknowledgements

When asked to revise the third edition, I initially thought that with the commercialisation of genetically modified crops and less funding for pesticide application research, at least in the United Kingdom, there was less need to revise the book. However, in the 12 years since the last edition, major legislative changes in Europe have reduced the range of pesticides now available and concerns about protecting the environment have increased. With this in mind, I asked Professor Paul Miller and Dr Roy Bateman to assist with specific chapters as they have been more closely involved in research on mitigating spray drift and the development of biopesticides respectively. Later, Professor Edward Law agreed to add his long experience to update the chapter on electrostatic spraying. I am indebted to all these specialists who have made a considerable contribution to this edition. I must also thank Graham Basil and Tim Neat for their help on granular application.

I would also like to thank the following for their contributions with supplying information and new illustrations for the fourth edition: Martin Baxter (TeeJet), John Clayton (Micron), Moira Hart (BCPC), Gillian Callaghan (GATE), Samuel Gan-Mor, Paul Hoyes (Kilgerm), Edward Law, Paul Miller (NIAB-TAG), Herb Nyberg (New Mountain Innovations), Tom Robinson (Syngenta), Tim Sander (Micronair), Graham Sanderson (Syngenta), Anugrah Shaw, Bill Taylor, Evan Thornhill, Robert Willey and Mick Hill (Househam). Most of the illustrations from the third edition have been retained, so I thank all those who supplied them.

I have been supported by Moira to whom I owe very special thanks.

Note

The author has endeavoured to ascertain the accuracy of statements in this book. However, facilities for determining such accuracy with absolute certainty in relation to every particular statement have not necessarily been available. The reader should therefore check local recommendations and legal requirements before implementing in practice any particular technique or method described herein. Readers will increasingly be able to consult the internet for information. Websites with information on pesticides are provided by international, government and commercial organisations as well as universities.

Graham Matthews and Roy Bateman manage the International Pesticide Application Research Consortium (IPARC) [www.dropdata.org]

Conversion tables

	A	B	A → B	B → A
Weight	oz	g	× 28.35	× 0.0353
	lb	kg	× 0.454	× 2.205
	cwt	kg	× 50.8	× 0.0197
	ton (long)	kg	× 1016	× 0.000984
	ton (short)	ton (long)	× 0.893	× 1.12
Surface area	in^2	cm^2	× 6.45	× 0.155
	ft^2	m^2	× 0.093	× 10.764
	yd^2	m^2	× 0.836	× 1.196
	yd^2	acre	× 0.000207	× 4840
	acre	ha	× 0.405	× 2.471
Length	µm	mm	× 0.001	× 1000
	in	cm	× 2.54	× 0.394
	ft	m	× 0.305	× 3.281
	yd	m	× 0.914	× 1.094
	mile	km	× 1.609	× 0.621
Velocity	ft/s	m/s	× 0.305	× 3.281
	ft/min	m/s	× 0.00508	× 197.0
	mile/h	km/h	× 1.609	× 0.621
	mile/h	ft/min	× 88.0	× 0.0113
	knot	ft/s	× 1.689	× 0.59
	m/s	km/h	× 3.61	× 0.277
	cm/s	km/h	× 0.036	× 27.78
Quantities/ area	lb/acre	kg/ha	× 1.12	× 0.894
	lb/acre	mg/ft^2	× 10.4	× 0.09615
	kg/ha	mg/m^2	× 100	× 0.01
	mg/ft^2	mg/m^2	× 10.794	× 0.093
	oz/yd^2	cwt/acre	× 2.7	× 0.37
	gal (Imp.)/acre	litre/ha	× 11.23	× 0.089
	gal (USA)/acre	litre/ha	× 9.346	× 0.107
	fl oz (Imp.)/ acre	ml/ha	× 70.05	× 0.0143
	fl oz (USA)/ acre	ml/ha	× 73.14	× 0.0137
	oz/acre	g/ha	× 70.05	× 0.0143
	oz/acre	kg/ha	× 0.07	× 14.27

Dilutions	fl oz/100 gal (Imp.)	ml/100 litres	× 6.25	× 0.16
	pint/100 gal (Imp.)	ml/100 litres	× 125	× 0.008
	oz/gal (Imp.)	g/litre	× 6.24	× 0.16
	oz/gal (USA)	g/litre	× 7.49	× 0.134
	lb/100 gal (Imp.)	kg/100 litre	× 0.0998	× 10.02
Density of water	gal (Imp.)	lb	× 10	× 0.1
	gal (USA)	lb	× 8.32	× 0.12
	lb	ft^3	× 0.016	× 62.37
	litre	kg	× 1	× l
	ml	g	× 1	× l
	lb/gal (Imp.)	g/ml	× 0.0997	× 10.03
	lb/gal (USA)	g/ml	× 0.1198	× 8.34
	lb/ft^3	kg/m^3	× 16.1	× 0.0624
Volume	in^3	ft^3	× 0.000579	× 1728
	ft^3	yd^3	× 0.037	× 27
	yd^3	m	× 0.764	× 1.308
	fl oz (Imp.)	ml	× 28.35	× 0.0352
	fl oz (USA)	ml	× 29.6	× 0.0338
	gal (Imp.)	gal (USA)	× 1.20	× 0.833
	gal (Imp.)	litre	× 4.55	× 0.22
	gal (USA)	litre	× 3.785	× 0.264
	cm^3	m^3	$\times 10^{-6}$	$\times 10^{6}$
	cm^3	μm^3	$\times 10^{12}$	$\times 10^{-12}$
Pressure	lb/in^2	kg/cm^2	× 0.0703	× 14.22
	lb/in^2	bar	× 0.0689	× 14.504
	bar	kPa	× 100	× 0.01
	lb/in^2	kPa	× 6.89	× 0.145
	kN/m^2	kPa	× l	× l
	N/m^2	kPa	× 0.001	× 1000
	lb/m^2	atm	× 0.068	× 14.696
Power	hp	kW	× 0.7457	× 1.341
Temperature	C	F	$\frac{9}{5}°C + 32$	$\frac{5}{9}(°F - 32)$

Pesticide calculation

(1) To determine the quality (X) required to apply the recommended amount of active ingredient per hectare *(A)* with a formulation containing ***B*** percentage active ingredient.

$$\frac{A \times 100}{B} = X$$

Example: Apply 0.25 kg a.i./ha of 5% carbofuran granules

$$\therefore \frac{0.25 \times 100}{5} = 5 \text{ kg granulates/ha}$$

(2) To determine the quantity of active ingredient (Y) required to mix with a known quantity of diluent (Q) to obtain a given concentration of spray.

$$Q \times \frac{\text{per cent concentration required}}{\text{per cent concentration of active ingredient}} = Y$$

(a) *Example*: Mix 100 litres of 0.5% a.i., using a 50% wettable powder

$$100 \times \frac{0.5}{50} = 1 \text{kg of wettable powder}$$

(b) *Example*: Mix 2 litres of 5% a.i. using a 75% wettable powder

$$2000 \times \frac{5}{75} = 133 \text{ g of wettable powder}$$

Units, abbreviations and symbols

A	ampere
atm	atmospheric pressure
bar	barometric pressure
cd	candela
cm	centimetre
dB	decibel
fl oz	fluid ounce*
g	gram
g	acceleration due to gravity (9.8 m/sec^2)
gal	gallon*
h	hour
ha	hectare
hp	horsepower
kg	kilogram
km	kilometre
kN	kilonewton
kPa	kilopascal
kW	kilowatt
L	litre
m	metre
mg	milligram

mL	millilitre
mm	millimetre
mm	micrometre
N	newton
µP	micropoise
P	poise
p.s.i.	pounds per square inch
pt	pint
s	second
V	volt
A	area
a	average distance between airstrip or water supply to fields
a.c.	alternating current
ADV	average droplet volume
AGL	above ground level
a.i.	active ingredient
AN	Antanov aircraft
BPMC	fenobucarb
C	average distance between fields
CDA	controlled droplet application
CFD	computional fluid dynamics
CU	coefficient of uniformity
D	diameter of centrifugal energy nozzle of opening of nozzle
d	droplet diameter

DCD	disposable container dispenser
‘D’	a standard size dry battery
d.c.	direct current
DMI	demethylation inhibitor
DUE	deposit per unit emission
EC	emulsifiable concentrate
EDX	energy dispersive X-ray
EPA	Environmental Protection Agency (USA)
F	average size of field
FAO	Food and Agriculture Organization of the United
FN	flow number
FP	fluorescent particle
GCPF	Global Crop Protection Federation
GIFAP	Fabricants de Produits Agrochimiques (International Group of National Associations of Manufacturers of Agrochemical Products)
GIS	geographical information system
GPS	global positioning system
GRP	glass-reinforced plastic
H	height
HAN	heavy aromatic naphtha
HCN	hydrogen cyanide
HLB	hydrophile-lipophile balance
HP	high power battery
HV	high volume
Hz	hertz

ICM	integrated crop management
ID	internal diameter
IGR	insect growth regulator
IPM	integrated pest management
IRM	insecticide resistance management
ISA	International Standard atmosphere
K, k	constant
kV	kilovolt
L	length
LAI	leaf area index
LD_{50}	median lethal dose
LERAP	local environmental risk assessment for pesticides
LIDAR	light detection and range
LOK	lever-operated knapsack (sprayer)
LV	low volume
MCPA	4-chloro-*o*-tolyloxyacetic acid
MRL	maximum residue level
MV	medium volume
N, *n*	number of droplets
NMD	number median diameter
NPV	nuclear polyhedrosis virus
OES	occupational exposure standard
P	particle parameter
PDS	pesticide dose simulator
PIC	prior informed consent

PMS particle measuring system
PPE personal protection equipment
PRV pressure-regulating valve
PTFE polytetrafluoroethylene
p.t.o power take-off (tractor)
PVC polyvinyl chloride
Q application rate (litre/ha)
q application rate (litre/m^2)
Q_a volume of air
Q_f quantity of spray per load
q_n throughput of nozzle
Q_t volume applied per minute
rev revolution
r.p.m. revolutions per minute
S swath
s distance droplet travels
SC suspension concentrate
SP single power battery
SMV spray management values
SR stability ratio
T temperature
T_r time per loading and turning
T_w turn time at end of row
TDR turndown ratio

TER	toxicity exposure ratio
U, u	wind speed
UBZ	unsprayed buffer zone
UCR	unit canopy row
ULV	ultra low volume
UR	unsulfonated residue
UV	ultraviolet light
V	velocity
V_f	velocity of sprayer while ferrying
V_s	velocity of sprayer while spraying
VAD	volume average diameter
VLV	very low volume
VMD	volume median diameter
VRU	variable restrictor unit
W	width
w	angular velocity
WG	water-dispersible granule
WHO	World Health Organization
WP	wettable powder
γ	surface tension
η	viscosity of air
ρ_a	density of air
ρ_d	density of droplet
$<$	is less than
$>$	is greater than