# VIEWPOINT

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## Standardization of Nematicide Application Rates[1]

D. W. DICKSON AND R. MCSORLEY[2]

*Key words:* application rate, calibration, dosage, nematicide, rate, standardization.

There is a need for scientists, regulating agencies, and industry to standardize procedures for calculating and reporting nematicide application rates. One finds few standards when reviewing publications or nematicide labels or discussing a nematicide testing protocol with industry representatives. The lack of agreement on procedures for reporting application rates leads to confusion and a lack of uniformity of testing. Also, comparing or understanding results may be difficult. We believe methods of calculating application rates should be standardized to facilitate comprehension and communication and to enable a rapid comparison of results. Our objectives are to review previous papers on the subject and offer clarification on calculating and reporting nematicide application rates under different application regimes.

### REPORTING APPLICATION RATES

There are many different nematicide formulations, methods and equipment for applying nematicides, and definitions of terms relating to nematicide application. Undoubtedly these have been important factors in the uncertainty that currently exists in the reporting of the actual nematicide rates used in experiments.

A review of recent publications in the *Journal of Nematology, Fungicide and Nematicide Tests,* and *Tests of Agrochemicals and Cultivars,* or of recent nematicide labels quickly reveals the confusion regarding nematicide application rates. In many publications, a single rate is given as g or ml per unit area (usually acre or hectare). At times one cannot determine whether it is a broadcast or row application rate, nor is the concentration per unit area that was used for calibration given. The latter is perhaps the single most important information on the rate that can be provided, yet it is generally omitted (1,6,8). In some cases no application rate is listed (7).

The actual pesticide labels also illustrate the lack of consistency in presenting nematicide application rates. For example, the 1987 Furadan 15G (Mobay, Kansas City, Missouri) and Mocap 15G (Rhone-Poulenc, Monmouth, New Jersey) labels list the application rates on corn as 2.4 oz a.i./1,000 linear ft, whereas the application rate on peanut is 2.2 oz a.i./1,000 linear ft. Both application rates are based on the row rate of 2.0 lb a.i./acre. The discrepancy in the rates is because corn was assumed to be grown on 40-in. row spacings in the midwestern United States, whereas peanut was assumed to be on 36-in. row spacings in the southeastern United States. Because of the lack of standardized methods for calculating nematicide rates, slightly higher calibration rates per unit area are calculated for corn than peanut.

The 1987 Temik 15G (Union Carbide, Research Triangle Park, North Carolina) label lists a different calibration dosage for each of three crops—potato, peanut, and cotton—because of variation in the row spacings, rather than listing a single sim-

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[1] Florida Agricultural Experiment Station Journal Series No. 8068.
[2] Department of Entomology and Nematology, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611.

plified rate that is consistent and uniform for all three crops. This is a paradox, because constant row spacings can no longer be assumed for any crop, in view of increased experimentation with and usage of narrow row spacings in a variety of crops (2,3,9,11).

Effective application rates of nematicidal compounds are determined experimentally by trial and error. Rates are most commonly determined as the amount of active ingredient used to treat a specified unit area or volume of soil and effectively reduce or otherwise affect plant-parasitic nematodes in that unit area to improve plant response. The application rate may be given as a range based on relative nematode population levels (low or high) at time of treatment.

Thus, once a nematicide rate is set for a specified unit area or volume of soil, it should not be affected by the method of calculation, method of application, or row spacing. Any alteration should be clearly stated and justified scientifically. The amount applied per unit area is critical because overdosage may increase chemical residue in crops that could result in harm to the consumer, the crop itself, or the environment, whereas underdosing could lead to failure of the chemical compound to effectively control the target pest.

Good et al. (4) were the first to suggest a guide for reporting application rates of nematicides. They state, "To prevent misunderstandings, application rates should be expressed as the amount of active ingredient used to treat a specified area or volume of soil. Preferably, the amount of active ingredients used should be given as milliliters or grams per 100 or 1,000 square feet of soil or linear feet of row along with the actual gallons or pounds per acre used. Reporting the amount of chemical used per 100 or 1,000 feet of row is particularly important in figuring dosages for in-the-row and band-row treatments where the amount applied per acre depends on the spacing between rows."

There are few other reports on the topic. Johnson (5) states, "Rates should be clearly and precisely stated," and Taylor and Sasser (10) provide a treatment that is based mainly on converting weights and measurements of rates from U.S. units to metric units. Although Good et al. (4) published their suggestions on calculating chemical application rates nearly 24 years ago, their suggestions are often not followed, and difficulty in interpreting rates remains a source of confusion.

## Standardizing Application Rates

Three distinct rates could be determined for most nematicide applications—calibration rate, row rate, and broadcast rate. The first of these, calibration rate, could be expressed either as a rate per linear distance of row (oz/100 ft, g/100 m), or on an area basis (oz/ft$^2$, g/m$^2$), which are not always equivalent. In addition, all three rates—calibration, row, and broadcast—are commonly used, and since their meanings and uses are different, their interrelationships must thus be clearly defined.

*Calibration rate:* This is the simplest, yet most important rate measurement. It results in a uniform concentration per unit of treated area or row length and allows one to quickly compare nematicide application rates. It is often used in practice for calibration, during which a measured amount of nematicide delivered by a hose, chisel, or meter (irrigation) is measured over time (e.g., as a tractor travels a specified distance). The amount may be reported as oz/ft, oz/ft$^2$ (g/m, g/m$^2$) or oz/100 ft, oz/100 ft$^2$ (g/100 m, g/100 m$^2$), with the latter a more practical consideration during the calibration process. This amount can be measured as a constant irrespective of row spacing. Application rate along a *linear* distance of row can be the same whether it is placed in-furrow, released under the soil surface as a narrow stream by a chisel, or placed on the soil surface in any band width. If the band width is changed, however, the concentration of nematicide delivered to a specified *area* along the row will change, unless the amount of nematicide applied is adjusted proportionally.

The choice of whether to calibrate consistent rates based on area or on linear distance depends on the properties of the nematicide used and on the biological nature of the control desired. As mentioned earlier, the rate per unit area of soil seems appropriate in obtaining a response to a nematode population distributed over an area or volume of soil, particularly in the case of soil fumigants or preplant applications of nonfumigant nematicides. If the nematicide is translocated through the plant such that the primary nematicidal action is systemic, rather than contact, then the total amount of active ingredient delivered in the root zone may be more critical. Assuming that a plant could take up the same amount of a nematicide from a small or a large band, then calibration along a linear distance of row becomes more meaningful. The most extreme example is the in-furrow application, which is essentially one-dimensional and must be calibrated along a linear distance, unless a "standard" band width is assumed, as was done by Good et al. (4), who assumed the treated area was 12 in. (30.5 cm) wide for row and in-furrow treatments. Obviously, it is always essential to state whether the calibration rate is per unit of linear distance (oz/100 ft, g/100 m) or per unit of area (oz/100 $ft^2$, g/$m^2$).

*Broadcast and row rates:* Fumigant or nonfumigant nematicides are either applied uniformly over a given area (*broadcast rate*) so that the entire area receives an equal concentration, or they are applied in bands of various widths over plant rows with the area between rows left untreated. In the latter case the treated area is usually only a small part of the total field area when one considers the untreated, unplanted space between rows. *Row rates* are reduced amounts of broadcast rates, where the rate is proportional to the broadcast rate, and is obtained by multiplying the broadcast rate by B/R, where B = band width and R = row spacing. Note that the broadcast rate is the same as the calibration rate per area, but expressed on a per acre or hectare basis.

There are variations in methods and equipment used to treat "in-the-row"; e.g., in-furrow, banded, strips, and sidedressing are common types of row treatments defined by Good et al. (4). Also, they state that the term overall treatment or application is preferred to the terms "broadcast," "solid," or "area" treatments when referring to treatments that cover the entire planting area. We prefer broadcast since the term is more widely used. The calibration rates and row rates of nematicides should be based on the broadcast rate in order to maintain a uniform concentration per unit treated area. Otherwise calculating the calibration rate from a row rate would give varying rates depending on the row spacings unless one assumed a standard row spacing when making such calculations. As stated in the introduction, history does not indicate that a standard row spacing is acceptable when making such calculations.

Row rates are rarely an important consideration for calibration purposes. Knowledge of this rate, however, can serve as a guide to the grower in estimating the amount of material needed for a specified field, and more important, some nematicide labels specify upper limits on the amount of material that can be applied per unit area (often presumably per broadcast area, but not always clearly defined).

## Determining Nematicide Rates

*Calibration rate:* Uniformity is needed in the methods used for calculating the application rates of nematicides. Simple formulae exist (4) for calculating the broadcast or row rates when the calibration rate is known. These same formulae can be transposed to give the calibration rate when the broadcast rate is known. However, calculating the calibration rate when only the row rate is given is a problem that causes confusion and uncertainty because of the various methods of row treatments and the large variance in row spacings used in agriculture. For standardizing nematicide

TABLE 1. Examples of dosages appropriate for rates reported for selected nematicides and methods of applications.

| Nematicide | Method of application | Type of rate | Dosage† Amount of active ingredient (U.S. units) | Dosage† Amount of active ingredient (metric units) |
|---|---|---|---|---|
| Aldicarb | At-plant in a 12-inch (30.5-cm) band, incorporated 2–3 inches (5.0–7.6 cm) deep with rolling tines, seed in treated zone. | Calibration rate per linear distance of row | 0.22 oz/100 ft | 20.5 g/100 m |
| | | Calibration rate per area | 0.22 oz/100 ft² | 67.3 g/100 m² |
| | | Broadcast rate | 6.0 lb/acre | 6.7 kg/ha |
| | | Row rate | 2.0 lb/acre | 2.2 kg/ha |
| | At-plant in a 6-inch (15.2-cm) band | Calibration rate per linear distance of row | 0.11 oz/100 ft | 10.3 g/100 m |
| | | Calibration rate per area | 0.22 oz/100 ft² | 67.3 g/100 m² |
| | | Broadcast rate | 6.0 lb/acre | 6.7 kg/ha |
| | | Row rate | 1.0 lb/acre | 1.1 kg/ha |
| | At-plant in an 18-inch (45.7-cm) band | Calibration rate per linear distance of row | 0.33 oz/100 ft | 30.8 g/100 m |
| | | Calibration rate per area | 0.22 oz/100 ft² | 67.3 g/100 m² |
| | | Broadcast rate | 6.0 lb/acre | 6.7 kg/ha |
| | | Row rate | 3.0 lb/acre | 3.4 kg/ha |
| | At-plant, in-furrow and covered with soil | Calibration rate per linear distance of row | 0.22 oz/100 ft | 20.5 g/100 m |
| | | Calibration rate‡ per area | 0.22 oz/100 ft² | 67.3 g/100 m² |
| | | Broadcast rate‡ | 6.0 lb/acre | 6.7 kg/ha |
| | | Row rate | 2.0 lb/acre | 2.2 kg/ha |
| Ethoprop | 7-day preplant, broadcast incorporated with the top 2–4 inches of soil (5.0–17.8 cm) immediately after application | Calibration rate per linear distance of row | 0.66 oz/100 ft | 61.5 g/100 m |
| | | Calibration rate per area | 0.22 oz/100 ft² | 67.3 g/100 m² |
| | | Broadcast rate | 6.0 lb/acre | 6.7 kg/ha |
| | | Row rate§ | 6.0 lb/acre | 6.7 kg/ha |
| 1,3-D: 10.1 lb/gal (1.21 kg/liter) | 7-day preplant, broadcast chisel injected 10 inches (25 cm) deep with a chisel spacing of 12 inches (30.5 cm) | Calibration rate per linear distance of row | 16.7 oz/100 ft | 1.55 kg/100 m |
| | | Calibration rate per area | 5.6 oz/100 ft² | 1.7 kg/100 m² |
| | | Broadcast rate | 152 lb/acre | 170 kg/ha |
| | | Row rate§ | 152 lb/acre | 170 kg/ha |
| Metham-sodium: 3.18 lb/gal (0.38 kg/liter) | 14-day preplant, broadcast, overhead sprinkler-irrigation applied in 1 acre inch water over a 4-hr period | Calibration rate per linear distance of row | 17.4 oz/100 ft | 1.63 kg/100 m |
| | | Calibration rate per area | 5.8 oz/100 ft² | 1.78 kg/100 m² |
| | | Broadcast rate | 159 lb/acre | 178 kg/ha |
| | | Row rate | 159 lb/acre | 178 kg/ha |
| | 14-day preplant, 18-inch wetted band, applied through a single drip-irrigation line per row in 1 acre inch of water over a 4-hr period | Calibration rate per linear distance of row | 8.7/100 ft | 0.81 kg/100 m |
| | | Calibration rate per area | 5.8 oz/100 ft² | 1.78 kg/100 m² |
| | | Broadcast rate | 159 lb/acre | 178 kg/ha |
| | | Row rate | 79.5 lb/acre | 89.1 kg/ha |

† A row spacing of 36 inches (0.9144 m) is used in all examples.
‡ To obtain area dosages, the in-furrow rate is assumed equivalent to that in a 12-inch (30.5-cm) band, as suggested by Good et al. (4).
§ Note that broadcast and row rates are identical for overall (broadcast) applications (B/R = 1).

rates, one should use only the broadcast rate for calculating the calibration rate. If only the row rate is given, then one has to know the calibration rate or the row spacing and band width used in calculating the rate before one can determine the calibration rate. Band widths should always be clearly stated, and if a fumigant is assumed to diffuse over a specific band width, then this assumed width should be mentioned.

Some examples relating the different rates are given (Table 1). It is evident from the figures that in any nematicide study rates used must be clearly identified. A statement of the calibration rate is essential, and appropriate band widths and row spacings should be reported to enable the reader to interconvert the different types of rates.

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