CHAPTER 5

CHEMICAL CONTROL

There is embraced under this heading a vast and widely scattered literature consisting of every possible intergradation between authority and quackery, detail and superficiality, circumstantial evidence and proof. It has taken the utmost effort and an inordinate amount of time to examine, edit, condense, and work into some semblance of suitability the multitude of facts, which together give us a fair conception of which chemicals, formulations, and methods hold the greatest promise for bringing under control our pestiferous terrestrial gastropods. Probably a fair share of responsibility for the many discrepancies in the literature in the field of economic malacology rests in the fact that too little is known about the bionomics of terrestrial mollusks; hence there is little in the way of "standards" upon which to base results of toxicological experimentation. Most often, it is the economic entomologist who is given the task of probing into the essentially unexplored field of malacological toxicology; it is therefore not strange that some of the results have a strong entomological flavor. Because there are so few who have worked in the field, and because of the general reluctance to do work in a strange field, there has been a tendency to "pass on" as authoritative the results, conclusions, and recommendations of earlier workers, and not always with proper credit, until only by virtue of frequency of appearance in the literature have certain methods become accepted as basic and standard. To make matters worse, some authors will incorporate into the recommendations, without adequate experimental testing, certain modifications which occur to them as being likely improvements. From another angle, nurserymen and even garden enthusiasts will make their own "discoveries," for which they do not have adequate testing facilities, and report upon them all too often in obscure publications. Discoveries of this sort not infrequently have real merit and warrant further investigation.

A very large portion of the literature in malacological toxicology concerns the problem of controlling medically important freshwater snails (Mozley 1952). Because of the aquatic medium and the special nature of the fluviatile and lacustrine environments, the requirements for a suitable molluscicide[1] are vastly different than for those of terrestrial snails and slugs. Hence, with only a rare exception, the present coverage of the literature has been limited to that which concerns the terrestrial forms. But even this has been difficult to classify. Under the circumstances it has seemed best to make summarizing comments under an alphabetically arranged series of subheadings based on the more important toxicants, with a small measure of cross reference. In the majority of cases, the less important toxicants have been grouped under such collective subheadings as "Attractants," "Contact Poisons," "Repellents." And, finally, an evaluation is made on the basis of the survey of the literature. This has been made with a twofold purpose: First, as far as possible, to put at the disposal of the reader the very best of, and all the help that, the literature has to offer so that he may determine what combination of known measures will best meet his needs under the circumstances in which he is working—especially where the giant snail is involved; and, second, to emphasize the disturbing paucity of truly dependable information, the serious chasms in our knowledge, and the genuine need for funds and qualified investigators to bring mollusk toxicology at least somewhere near equality with insect toxicology. For over twenty years, no molluscicide of a spectacular nature has been discovered. Progress has largely been limited to modifications in formulation and application. This is indeed a sad state of affairs in a field destined to play a proportionately greater role in our agricultural economy!

Chemicals and Compounds

Alum (potassium aluminum sulphate): Anderson and Taylor (1926) dusted this chemical on the slugs *Deroceras reticulatum* with completely negative results, but sprinkling with an aqueous solu-

[1] In the American literature especially, there is a tendency to spell this word "molluscacide"; but, both orthographically and etymologically, such spelling is not acceptable. The recent introduction of the hybridized word "snailicide" is unfortunate.

tion was reported to be lethal to both snails and slugs (Anon. 1930). According to Merrill (1929, 1930), in regions where calcium arsenate–bran baits are in competition with green vegetation, Storer found that a spray, consisting of ½–1 lb. of either potassium alum or ammonium alum in a gallon of water, was superior as a killer of slugs. Smeaton and Smeaton (1906) compounded and patented a vicious but apparently unsuccessful formulation of powdered alum, coconut fiber, silver sand, and—ground glass!

Aluminum Sulphate: The use of this chemical as a molluscicide was first recommended by Durham (1920). Hodson (1924) suggested that by combining 1 lb. with 5 gal. of saturated solution of quicklime in water, the scorching effect on the vegetation could be overcome. Later (1925), he recommended a 1:2 by weight powder mixture with lime, broadcast at the rate of *ca.* 56 lb. per acre, as giving "very efficient control" of *D. reticulatum;* but he emphasized that it was not practical on a large scale both because of the high cost and the damage to young foliage. Similarly, MacDougall (1931) found aluminum sulphate impractical as a molluscicide; and in the same year, Miles *et al.* failed to find it lethal to the slug *Milax sowerbii.*

ARSENICALS[2]

Calcium arsenate: Lovett and Black (1920) tried a great many different chemicals in the control of *D. reticulatum* and found $Ca_3(AsO_4)_2$, both as a dust and a spray on chopped lettuce leaves, to be the best. Basinger (1923*a, b,* 1927) modified the recommendations of Lovett and Black and developed, in the control of *Theba pisana,* a highly effective calcium arsenate–bran bait (1:16 by weight, made moist, but not wet, by water and scattered 1 lb. of bait to approximately 1,458 sq. ft.). He warned that this is a slow acting poison and that its effectiveness should not be judged until two to three days after it has been scattered. This period should apparently be extended to four days in the case of *A. fulica* (van Weel 1949). Basinger found, however, that calcium arsenate used as a dust was of no value in controlling *T. pisana.* He later showed (1931) that the calcium arsenate–bran bait could be used with equal success on *Helix aspersa* (cf. Anon. 1949*h*). Lewis and LaFollette (1941) labeled it the best bait for this species, although Hely (1946) warns that it will cause considerable fruit and leaf fall if, as recommended by Lewis and LaFollette (1942*a, b*), it is scattered in the trees during periods of high humidity. A combination

2 See also *Paris green.*

of 25 lb. of bran, 2 lb. of calcium arsenate, ¾ gal. of molasses, and 1 gal. of water (or 2 lb. of sugar and 1½ gal. of water), produced a reported 99 per cent kill of *T. pisana* in South Africa (Joubert and Walters 1951). If slugs were also involved, it was suggested that there be added to the above formulation ½–1 lb. of meta fuel or 6 pints of methylated spirits. Lange and MacLeod (1941) found that the mixture of calcium arsenate and metaldehyde was more effective than either chemical alone. The failure of Persing (1944*b*) to concur in this conclusion was later explained by Lange and Sciaroni (1952) when they warned that increasing the metaldehyde from 1 per cent to 5 per cent by weight in arsenical baits produces a repellent effect. More and more, however, it is being recommended that metaldehyde baits be fortified either with calcium arsenate or sodium fluosilicate (e.g., USBEPQ 1953).

A number of investigators have explored the possibilities of using calcium arsenate in the control of *A. fulica.* Beeley (1938*a*) recommended Basinger's formula for the control of this species in Malaya and gave comparative cost figures. FitzGerald (1947) supported this recommendation. Pangga (1949), however, found it not very attractive to the giant snail. He tried the powdered calcium arsenate on banana peel, but it had no effect; in contrast, van Weel (1949) found the powder very effective. Since the snails are attracted to and will consume lime, Corbett (1937) suggested the use of balls of lime poisoned with calcium arsenate and, similarly, Rees (1951) recommended a 1 per cent solution of this poison sprayed on lime covered walls. The creation of a longer lasting bait by the addition of cement to the calcium arsenate–lime mixture was first suggested and favorably reported upon by Leefmans (1933*c*). Its use was strongly recommended by Garnadi (1951); but Fairweather (1937) had "little success" with this new type of bait. Beeley (1938*a*) recommended a fairly strong bait consisting of one part of calcium arsenate, six parts of slaked lime, and two parts of cement by volume (or 1:4:2 by weight) and sufficient water to form a consistency of ordinary concrete mix. This was dried in thin slabs, broken into small pieces and scattered in the areas frequented by *A. fulica.* A considerably stronger formulation (8:11:1 by weight plus water to make a thin paste) has been effectively used for the past several years as one of the chief means of combating this snail in Hawaii (Fullaway 1949). This mixture is painted on rocks, posts, tree trunks, and the like. Where there are no such objects, stones or cinders are coated with the mixture and broadcast; or wooden lath is painted with the mixture and placed on the ground as a barrier (Thistle 1954*b*). According to Thistle (1953*b*) and Weber (1954), better results have been obtained when small coated stones (¾–1 inch in diameter) were placed two feet apart than when the same weight of large stones (about 2 by 4 inches) were placed ten feet apart. Similar methods are currently being used in a number of other areas including Ceylon (Mead 1955*b*) and New Guinea (where they use crushed coral instead of lime). Because of the high coralline content of the soil in Guam, however, the snails were not sufficiently attracted to the poisoned whitewash to make it effective as a method of control (Peterson 1957). Chipman and Seibert (1939) have patented a molluscicide which combines calcium arsenate and Paris green.

Lead arsenate: Lovett and Black (1920) found that slugs would readily eat this poison, but few were killed by it. Torres (1950) recommends its use with sugar and wheat bran (1:1:10 ratio by weight) as a bait to kill the giant South American snail (*Strophocheilus oblongus*) in coffee plantations. Cameron (1951) and Araujo (1952) recommend similar formulations. A weaker formulation (1:2:17) is claimed by Pereira and Gonçalves (1949) to give an 88 per cent kill of slugs and snails; the addition of 2.5 per cent metaldehyde and the substitution of honey for sugar made no significant improvement in the bait.

Sodium arsenate: It is not readily eaten by slugs and tends to blacken lettuce bait (Lovett and Black 1920).

Sodium arsenite: This chemical ("penite" is a 40 per cent commercial solution) was used in the form of a spray in early, futile attempts in 1946 to eradicate *A. fulica* in Guam. More recently it has been used quite successfully as a 1 per cent spray (i.e., a 2½ per cent "penite" solution) against this same pest in Hawaii, especially where infestations are heavy (Lennox 1953, Weber 1954). Later, the spray was used as a 0.5 per cent solution with no reduced effectiveness (Thistle 1953*b*). Experiments conducted by Q. C. Chock (*in litt.* Jan. 7, 1946) gave strong indications that poisoning was effected through absorption by the foot, although Weber assumes that some have been killed by ingesting the poison-covered leaves. Since much of the vegetation dies within a few days after being sprayed, this chemical is generally considered a "weed killer" (cf. Basinger 1927). Its highly toxic nature makes it dangerous to use under most conditions where the snail is found. Furthermore, it is expensive to use, even under limited conditions, and a rain quickly dispels its effectiveness.

White arensic: This was found not to be eaten readily by slugs; when it was eaten, the kills were low (Lovett and Black 1920). Pangga (1949) found it ineffective in the control of *A. fulica.*

Ashes: In the control of *A. fulica,* ashes or a suitable substitute (e.g., sawdust, charcoal, cinders, etc.) as a repellent barrier have been recommended by many, including Green (1910*c*), Hutson (1920), South (1926*b*) and Corbett (1933). Most often, it is suggested that they be used in combination with copper sulphate (*q.v.*). The continued use of ashes introduces the danger of moving the soil pH too strongly in the alkaline direction.

ATTRACTANTS[3]

Bran of wheat, rice, or other grains is almost the universal attractant (*vide* Diluents) in snail and slug baits in spite of the fact that its availability and cost vary considerably from area to area. Lewis and LaFollette (1941, 1942*a, b*) and Persing (1944*a*) found in southern California that fresh orange pulp (in a 20–25:1 by weight ratio with calcium arsenate) was about equally effective in controlling *H. aspersa* in citrus groves but only one quarter as expensive as when bran was used. A combination of equal parts of bran and pulp was shown to be more effective than either one alone. The dried pulp however proved to be inferior to bran. On the other hand, dried citrus peels have been demonstrated to be effective both as an attractant and a diluent. Lime and calcium carbonate in various forms have been used as attractants in a number of poison baits, but particularly in those containing calcium arsenate and/or metaldehyde (*q.v.*). Metaldehyde itself has been considered by many to be a specific attractant for snails and slugs under proper conditions. A great many different substances were recently tested in Hawaii in an effort to find an effective, practical attractant for *A. fulica.* Metaldehyde emerged as the only one with any real possibility (Thistle 1953*b*, 1954*b*); and even this in the dry form or in solution proved to be "entirely negative" in these experiments, as was wheat bran in either the dry or fermented state. Many commercial bait preparations contain amyl acetate as an attractant.

Barium Fluosilicate: A spray of this chemical was used in attempt to control *H. aspersa* in citrus groves in Australia but was not

[3] The less commonly used term "attrahent" is not used here because of its medical connotation suggesting, antithetically, an irritant.

found to be effective enough to be of value (Hely 1946). Levy (1938) patented a snail poison containing this chemical and metaldehyde.

Benzene Hexachloride (BHC): Pereira and Gonçalves (1949) mentioned without elaboration that for killing snails and slugs, this chemical was inferior to metaldehyde. On the other hand, Rao *et al.* (1953) reported that a 5 per cent dust broadcast about 25 lb. per acre of drained paddy was superior to a 2 per cent metaldehyde bait in that it "killed most of the snails in the fields." Pappas and Carman (1955) found it slightly less than moderately effective in killing *H. aspersa.*

Bordeaux: This mixture of lime and copper sulphate was shown to be an "excellent repellent for slugs and non-injurious to foliage" (Lovett and Black 1920). Miles *et al.* (1931) similarly recommended its use. It was found to be only of limited use however in repelling *H. aspersa* (Lewis and LaFollette 1941). Similarly, Basinger (1927) discontinued its use against *T. pisana* because it did not give desired results. On the other hand, a spray consisting of a Bordeaux mixture (2:2:80), white oil emulsion (1 gal.), and nicotine sulphate (¾ pint) was found to be more effective than any other control measure of *H. aspersa* in citrus groves in New South Wales (Hely 1946). Later reports (Anon. 1949*h*) suggested the omission of the nicotine sulphate and pointed out that the spray not only had a considerable knockdown effect on the small snails, but this effect was retained in a residual fashion for a period of several months. Pangga (1949) reported that a spray of this mixture was toxic to only the young specimens of *A. fulica.*

Carbon Disulfide: This gas was used in Sidney, Australia, to refumigate (after hydrocyanic acid gas treatment) a shipment of copra infested with *A. fulica* (Harrison 1951).

Chlordane: Pappas and Carman (1955) demonstrated in field tests that this insecticide is of essentially no value in the control of *H. aspersa.* Pangga (1949) reported without elaboration that the "Octaklor spray" had toxic effect upon only young *A. fulica.*

Coal tar: The use of tarred coconut fibers around the trunks of fruit trees to protect them from the attacks of *A. fulica* was apparently first reported by Green (1910*c*) and reiterated by Hutson (1920) and van Weel (1949). G. S. Dun (*in litt.* April 21, 1952) put a ring of coal tar around plantings in his own yard in New Guinea; this very successfully and inexpensively repelled the giant African snails. The rapid growth of weeds, however, demanded replacement about every two weeks. In Ceylon, R. C. L. Notley (*in litt.*

Dec. 7, 1950) succeeded in keeping the tar moist by mixing it with old engine oil. Boards painted with this mixture and laid about the garden formed an effective barrier against this snail.

Contact Poisons

Carbolic acid (*vide* Phenol), cedar oil emulsion, clove oil emulsion, gasoline, nicotine sulphate, nicotine resinate, oil of lemon, oil of tar emulsion, sodium hydroxide, sulphur and tobacco dust were used by Lovett and Black (1920) in various combinations and concentrations on the slug *D. reticulatum* with varying results. Even with this small naked gastropod, these substances were considered to be of "decidedly minor value in practical field work."

Another series of chemicals was tried by Hodson (1924) in an attempt to find a good contact poison for slugs. The following were without effect: dichlorbenzene (10 per cent sol.), potassium bichromate (10 per cent sol.), derris powder, derris solution, mustard (brown) solution, and sodium silicofluoride (10 per cent sol.). Potassium xanthogenate solution, sodium hyposulphite (10 per cent sol.) and, very strangely, copper sulphate (10 per cent sol.) were reported as having only transient effects. Chloral hydrate (10 per cent sol.) proved to be irritant, but its cost made it economically impractical; on the other hand, borax was "extremely lethal" but it was destructive to vegetation.

Miles *et al.* (1931) tried still other substances on the slug *Milax sowerbii*. Dusting specimens of this species with the following did not prove lethal: aluminum sulphate, ammonium chloride, copper carbonate, copper sulphocyanide, flake naphathlene, flowers of sulphur, green sulphur, lead sulphocyanide, potassium permanganate, precipitated chalk with chlorcresylic acid, precipitated chalk with creosote, sodium nitrate, thiourea, and "used" calcium carbide. On the other hand, they found that the following substances would kill the slugs within a few minutes after being dusted on them: ammonium sulphate, ammonium sulphocyanide, barium sulphocyanide, calcium carbide, calcium cyanide, corrosive sublimate, drained creosote salts, potassium sulphocyanide, sodium carbonate and sodium sulphocyanide. Of these, only calcium cyanide was sufficiently lethal at practicable concentrations to be considered for use in field conditions; its very deadly nature, however, makes serious consideration completely out of the question. Mixing ammonium sulphate with steamed bone flour gave negative results as a contact poison for slugs (Anderson and Taylor 1926). More recently, Lange and Sciaroni (1952) reported that dusts of hydrated lime, cupric oxide, and nicotine were effective as contact molluscicides for only a short period of time. The insecticide hexaethyl tetraphosphate (HETP) was ineffective as an aerosol in fumigating greenhouses infested with snails (Smith *et al.* 1948). A Russian patent suggests that a spray consisting of at least a 0.1 per cent aqueous solution of ethylene chlorohydrin (2-chloroethanol) will kill slugs (Paĭkin *et al.* 1949).

Copper sulphate, Bordeaux mixture, and metaldehyde may be classified as contact poisons, but they have been treated in detail under separate headings.

Copper Compounds[4]

The following compounds of copper were used in aqueous solution of 1 per cent or less by Lovett and Black (1920) in an attempt to find a control for the slug *D. reticulatum:* acetoarsenate, benzoate, carbonate, chloride, chromate, cyanide, ferrocyanide, and sulphate. Only the chloride and sulphate compounds produced a burning of foliage. The results of their experiments caused them to dismiss summarily all of these compounds as having no promise in slug control. Basinger (1927) found the use of $CuSO_4$ impractical in the control of *T. pisana* because it caused damage to plants. Using lower concentrations of this chemical, MacDougall (1931) reported effective control of slugs with no damage to plant foliage. Anderson and Taylor (1926) similarly recommended as a "deadly" control for slugs a 4–6:100 by weight mixture of $CuSO_4$ in the less toxic kainite fertilizer (hydrous potassium-magnesium chlorosulphate), distributed 2–3 hundredweight per acre. Miles *et al.* (1931), after considerable experimentation with this chemical, cautiously suggested that a precropping treatment with crystalline $CuSO_4$ at the rate of one hundredweight per acre might bring protection from the slug pest *M. sowerbii;* but they warned against damage to foliage if this chemical is broadcast after the crops have come up. To prevent slug migration, they recommended sprinkling peripheral ditches with $CuSO_4$ or a mixture of this chemical and ground limestone. For slug control Lange and Sciaroni (1953) suggested a dust containing monohydrated copper sulphate and hydrated lime in a 20:80 ratio.

These and other experiments with $CuSO_4$ focused attention upon this chemical in early attempts to control *A. fulica.* Green (1910*c*), Hutson (1920), South (1926*b*), Corbett (1933), and Fernando (1952) have recommended its use in almost every conceiv-

[4] *See also* Bordeaux, Paris green.

able manner; shallow ditches around gardens were filled with wood ashes, coconut fiber dust, or sawdust treated with a 4–10 per cent solution of $CuSO_4$; some of this same mixture was spread around small beds and individual special plants; coir ropes were treated with 10 per cent solution and placed around vegetable gardens and around the bases of trees; small crystals of $CuSO_4$ were placed at the surface of the ground near plants needing special protection; a solution consisting of one lb. of $CuSO_4$ to ten gal. of water was sprinkled on the ground where the giant snails were numerous; stone walls specially constructed around vegetable gardens were watered two to three times a week with a solution of one lb. $CuSO_4$ in a gal. of hot water; and snails collected by hand were first drowned in a 4 per cent solution before being discarded. To insure against attacks by *A. fulica* in Ceylon, the sticky seeds of the cacao are rolled in a mixture of $CuSO_4$ and ashes before being planted (R. C. L. Notley *in litt.* Dec. 7, 1950). Pangga (1949) tried 1–10 per cent solutions of $CuSO_4$ on giant snails and found that, although the young individuals were readily killed, only a few adults were affected.

The copper-based commercial fungicides, Greenol, Omazene, Crag 658, Cunimene 2243 and Corona 53 all failed to control slugs without phytotoxic effects (Karlin and Naegele 1958).

Corrosive Sublimate: A 1:1000 aqueous solution proved "highly efficient as a repellent" in combating *M. sowerbii* (Miles *et al.* 1931). This recommendation has subsequently been indorsed by a number of investigators. Even in low concentrations, however, this is a dangerous chemical to use.

Creosote: One per cent mixture of creosote in precipitated chalk gave "outstanding" results as a slug repellent (Miles *et al.* 1931).

Cryolite (*sodium fluoaluminate*): This spray was shown by Lewis and LaFollette (1941, 1942*a, b*) to be of little value in controlling *H. aspersa* in California citrus groves. The same conclusions were announced by Hely (1946) in Australia.

DDT: The few experiments which have been performed to determine the possible molluscicidal properties of this insecticide indicate definitely that further experimentation is needed. Buckhurst (1947) had at first only slightly encouraging results with the 0.1 per cent aqueous emulsion, the 5 per cent dust, and the "DDT bait." Slugs did not touch the bait and only very slight kills were produced by the dust and the emulsion; there was however a very clear deterrent effect. But when he increased the strength of the emulsion to 0.2 per cent and applied it at the rate of 2 gal. per 100 sq. yd., he found it produced "an excellent control of slugs without damage to growing cabbage plants." It was determined that the killing power of the application was retained for at least two weeks. Thomas (1948) tried a DDT-bran bait and found that although the slugs were attracted to it (undoubtedly because of the bran, *vide* Attractants), they were not killed by it. This insecticide in a kerosene emulsion was tried in an undisclosed percentage on *A. fulica* by Pangga (1949); young specimens were killed but the adults remained unaffected. Frömming (1949, 1950) and later Frömming and Riemschneider (1952) and Frömming and Plate (1952) failed to demonstrate any molluscicidal action in preparations of DDT and other insecticides. Hely (1946) found DDT of essentially no value in controlling *H. aspersa* in citrus orchards in Australia; Pappas and Carman (1955) concurred in this. Pereira and Gonçalves (1949) and Karlin and Naegele (1958) tried it on slugs and snails but did not recommend it. When it was used as an aerosol to fumigate snail infested greenhouses, it proved to be ineffective (Smith *et al.* 1948).

Dieldrin: W. H. Lange, of the University of California at Davis, has indicated in a preliminary report (*in litt.* Jan. 29, 1952) that, even when combined with metaldehyde (*q.v.*), the action of dieldrin on *H. aspersa* suggests that it has relatively little value as a molluscicide. Pappas and Carman (1955) concur in this. Karlin and Naegele (1958) found it "ineffective" in controlling slugs in greenhouses.

Diluents

The most desirable diluent in snail baits is one that acts as an attractant (*q.v.*) and is relatively inexpensive. Wheat bran has long been the diluent of choice, especially in metaldehyde and calcium arsenate baits. More recently, apple pomace has been successfully used, particularly in a 1:1 combination with wheat bran. In the Orient, in particular, rice bran is more commonly used; and although it has been reported to be less good than wheat bran, its much lower price makes it more economical to use (Callan 1941). Coconut meal, corn meal, rice husk, sawdust, and other diluents have been used with lesser varying degrees of success. Sawdust in particular is of uncertain value because of the aromatic nature of some wood, even when thoroughly seasoned. In cases where only a mediocre diluent is available, some compensation may be made through the addition of an attractant, for example, amyl acetate.

Ethylene Dibromide: This was shown by Balock (1951) to be seventeen times as effective as methyl bromide in killing immature stages of the oriental fruit fly in papaya. It is immediately apparent that serious consideration should be given to the replacing of methyl bromide, carbon disulphide, and hydrocyanic acid gas (*q.v.*) by this more toxic chemical in the fumigation of snail infested cargoes.

Ferrous Sulphate: When specimens of *T. pisana* were placed on a surface dusted with an approximately 80 per cent proprietary mixture of this chemical, they displayed great irritation, withdrew into their shells for four weeks, but remained alive (Basinger 1927). Pierce (1931) enthusiastically recommends dusting this chemical about the garden to kill slugs and snails indicating that not only are good kills obtained but the chemical itself is a plant food and stimulant.

Gammexane (gamma isomer of hexachlorocyclohexane): Two investigators report on the use of this chemical in the control of *A. fulica.* Pangga (1949) states without elaboration that gammexane was "ineffective." In direct contrast, J. A. Tubb states (*in litt.* Jan. 8, 1952) that it is "effective" in North Borneo. Since this insecticide imparts an off-flavor to fruits and vegetables, it at best would be of limited use. Frömming and Riemschneider (1952) report that HCH was ineffective on limacine slugs both as a contact poison and a stomach poison.

Hydrocyanic Acid Gas: The Bureau of Plant Quarantine in California has used this gas to fumigate the holds of ships infested with *A. fulica.* It was used for the same purpose in Vancouver, British Columbia (*in litt.* W. Reed Mar. 9, 1951; cf. Zuk 1949), and in Sydney, Australia (Harrison 1951).

Isolan: This toxicant was found to be considerably more effective as a molluscicide than any of 31 other promising chemicals tested by Pappas and Carman (1955). Both as a spray and a bait it approached metaldehyde in effectiveness.

Kerosene Emulsion: This was tried, in a manner not indicated, by Pangga (1949) on *A. fulica* and was found unsatisfactory inasmuch as it was toxic only to the young snails.

Lime: Dusting hydrated lime, $Ca(OH)_2$, about slug infested plants (Massee 1928) or even on the slugs as a contact poison (Anderson and Taylor 1926) gave unsatisfactory results, especially since some plants may be damaged in the process (Anon. 1930). Blauvelt (1952) suggested that $CuSO_4$ be added to the lime; and similarly, Lange and Sciaroni (1953) report that lime has only transient value unless it is combined with 20 per cent monohydrated copper sulphate (*vide* Bordeaux). Pangga (1949) combined it with sulphur and tested it on *A. fulica,* but it proved toxic only to immature specimens. Where lime is lacking or low in the soil, it can be used successfully as an attractant (*q.v.*) in snail baits; but its prolonged use in acid soils, or the practice of "liming" soils, in general creates a more favorable environment for snails (Atkins and Lebour 1923*a, b*).

Metaldehyde: According to Gimingham (1940), this chemical was first used as a molluscicide in 1934 in South Africa, although it apparently was not used in this manner in England until 1936 (Jary 1939). In an earlier work by Gimingham and Newton (1937) and in a fairly complete summary by Barnes and Weil (1942), there is indicated much uncertainty, approaching the legendary, as to just how the molluscicidal properties of metaldehyde were discovered. It is an inflammable polymerized form of acetaldehyde with a chemical formula of $(CH_3CHO)_4$, and is the chief constituent of the solid, commercial "meta fuel," a form in which it is often sold. Its solubility in water is low in the extreme—being 0.018 per cent at 0.5° C., 0.020 per cent at 17° C. and 0.026 per cent at 30° C.—with no detectable tendency to depolymerize in neutral or alkaline aqueous solutions even after standing for over six months (Cragg and Vincent 1952).

There is no unanimity among investigators as to just what is the action of metalhyde on various mollusks. Many agree that it is a specific attractant. This was early questioned by Jary (1939). It was further questioned by Corbett and Pagden (1941), who announced that individuals of *A. fulica* will crawl toward bait containing metaldehyde and then change their course just before they get to it. Weber (1954) reported that in carefully controlled experiments dry metaldehyde and metaldehyde "in solution" failed to attract *A. fulica.* Lewis and LaFollette (1942*a, b*) went a step further by concluding that under certain conditions it is actually repellent to *H. aspersa.* Lange and Sciaroni (1952) explained this and warned that in higher concentrations, metaldehyde becomes a repellent. Lewis and LaFollette further concluded that slugs are more susceptible to metaldehyde than are the snails. Gammon (1943) drew the same conclusion; but Thomas (1948) suggested that just the reverse is the case.

Jary and Austin (1937) were apparently the first to conclude that metaldehyde is both a contact and a stomach poison. This conclusion was supported by Cameron (1939) and Lange and

MacLeod (1941). In contrast, Thomas (1948) believed that the action of metaldehyde, as far as snails are concerned, is entirely that of a stomach poison. And inversely, he explained that the action on slugs is threefold, viz., an irritant effect, causing excessive production of mucus, from which the slug will recover if it is washed off and kept from desiccating air; an anaesthetic effect causing complete immobility except under the most severe stimulation; and last, an irreversible, lethal, toxic effect which produces a characteristic transparency in the gut wall. The classical work of Cragg and Vincent (1952) confirms some of Thomas' conclusions and disproves others. They demonstrate indisputably that metaldehyde is not only a contact and a stomach poison, but that it has a progressively greater toxic action in the haemocoele, in the crop, and on the surface of the body; hence they recommend its greater use as a contact agent. They could not confirm a "characteristic" transparency of the gut wall emphasized by Thomas. Nor could they detect any fumigant action. However, they did indicate that as a physiological reaction to metaldehyde, there is a loss of water which continues even under conditions of 100 per cent relative humidity.

Lange and MacLeod (1941) stated that metaldehyde will produce greater kills of slugs and snails in unshaded areas because of the killing action of the sun on the "stunned" individuals. Essentially the same explanation was made by Woglum (1943) and later by Persing (1945*b*), who reported that a substantial percentage of *H. aspersa* will recover from metaldethyde poisoning during cloudy weather or in the shade (cf. Lewis and LaFollette 1942*a, b*). Although the same reason is not given by Corbett and Pagden (1941), they imply reaching the same conclusions through their recommendation that less meta is needed for *A. fulica* when the bait is placed in exposed places. Later Lange and Sciaroni (1952) stated that "in protected situations metaldehyde does not seem to be an active enough poison to give high mortalities when used alone in baits." Lange subsequently determined that an excessively high concentration of metaldehyde stuns the snail before it can consume a lethal dose.

Under conditions of high relative humidity, Lange and MacLeod obtained greater kills, but Stringer (1946) reported less favorable results because of the greater recovery of the slugs. Thomas (1948) explained that when metaldehyde is used during warm, wet weather, there will be a greater number of slugs caught but only a small percentage of them will be killed; and inversely, during cold, dry nights, the number caught will be smaller but the percentage of kill will be larger. From this he concluded that the maximum kill can be obtained when metaldehyde is used during wet, warm nights which are followed by dry, warm days. Again, Cragg and Vincent (1952) beautifully elucidated the several points of apparent confusion. First, they indicated that metaldehyde intoxication causes immobilization, inhibition of feeding, and a loss of water through secretion of mucus. Under optimum conditions of high humidity and low temperature, the snails and slugs may recover. But with low humidity, there is a greater loss of water and death ensues. High temperatures similarly produce a greater incidence of death through the greater uptake of poison, the increased toxic action, and the greater activity of the snail. It should be pointed out, however, that increased activity of the snails, and therefore increased opportunities for contacting the metaldehyde, depends not only upon a higher temperature but a concomitant high humidity—which high humidity, ironically, reduces the killing effect of metaldehyde! Moreton (1953) takes advantage of this information by suggesting that during dry weather, lower concentrations of metaldehyde may be used effectively. And conversely, it is recommended that during cool, wet weather metaldehyde baits be fortified either with calcium arsenate or sodium fluosilicate (USBEPQ 1953). The more recent works on this subject unfortunately seem to neglect the important factor of the killing action of the sun; hence the ideal conditions, as set forth by Thomas, should be amended to read, "*clear,* dry warm days." Apparently because of the confused picture presented by the interplay of several of the irregularly variable ecological factors, some German investigators have come to question seriously the reliability and practicability of metaldehyde baits (Frömming 1951, 1952*b;* Frömming and Plate 1952; Plate and Frömming 1952), although Trappmann (1952) in rebuttal stoutly defends their use. Lange (*in litt.* Feb. 14, 1956) adds a welcome clarifying note with the following words: "In my experiments I can get from practically no control with metaldehyde to 100 per cent kill within a few feet difference in location, depending upon whether the affected mollusks are exposed to desiccatory conditions or to high humidities. The variations in results with metaldehyde I am convinced are due to the multiple and variable climatic conditions prevailing at any particular time."

A variety of "carriers" were tried with metaldehyde by Barnes and Weil (1942) in an attempt to formulate a more effective bait. Considering practicability and percentage of kill, none proved more promising than the old standby, wheat bran. At first, an excessively strong formulation of 1:2–1:2½ was used (Newton 1937). Shortly after that, however, it was decided that a bait of approximately the following proportions was adequate: ⅓ oz. "meta," 1 lb. bran, and 1 pt. water (Cameron 1939, Esslement 1938, Thomas 1944, *et al.*). Without the water, the bait is considerably less effective (Pereira and Gonçalves 1949). It has been suggested (Anon. 1949*h*) that to the above formulation 1 oz. of calcium arsenate or ½ oz. of Paris green be added for a greater kill. Reflecting a very definite, recent trend, a stronger bait has been recommended by the USDA through the USBEPQ Farmers Bulletin No. 1895 (1953) in that to a mixture of 1 oz. of metaldehyde and 2 lb. of wheat bran, corn meal, or similar material, there be added either 2 oz. of calcium arsenate or 1 oz. of sodium fluosilicate. This mixture is moistened with water just before use and applied to small gardens at the rate of 1 lb. per 1,000 sq. ft. or 40–50 lb. per acre in larger areas. On large scale operations, it is recommended that the bait be machined into pellets and broadcast at the rate of 5–10 lb. per acre. The addition of lead arsenate and honey to the metaldehyde-bran mixture apparently makes no improvement in the bait (Pereira and Gonçalves 1949). Putting sugar or molasses in the basic formula did not increase significantly its attractiveness as a bait but it did increase the percentage of kill (Thomas 1948). But baits of this sort understandably spoiled more quickly.

In an attempt to overcome some of the difficulties of a mealy bait, Thomas made bait "biscuits" by combining plaster of Paris (dry), metaldehyde, and bran in a 1:1:10 proportion by volume, mixing, adding water to permit molding into 3 by ¼ inch discs, and sun-drying until completely hard. These proved to be more attractive to slugs but they produced less of a lethal effect than the standard mix. Substituting casein glue for plaster of Paris made the "biscuits" more attractive and more lethal only to slugs with carnivorous proclivities. A formula for a more conventional biscuit is under British patent (Boot's *et al.* 1939). In addition to metaldehyde, the biscuits contain bran, flour mucilage, lard, and a leavening agent, and are baked at about 130° F. to avoid volitalization of the metaldehyde. Another novel, but dubiously effective, approach to the problem of making a "lasting" bait was made by Beekler (1944) who suggested that finely divided metaldehyde be suspended in paraffin!

Ever since shortly after its discovery as a molluscicide, considerable use of metaldehyde has been made in combating *A. fulica.* In fact, there undoubtedly is no infested area of any appreciable size in which metaldehyde has not been tried in some form or combination. Beeley (1938*a*) in Malaya was probably the first to suggest its use for this pest. He recommended a 1:64–1:32 (1.6–3.1 per cent) mixture, by weight, with rice bran, moistened and distributed three pounds to the acre. Dias and Thamotheram (1939) and Fernando (1952) in Ceylon made similar recommendations but indicated more specifically the addition of approximately 26 oz. of water (about 1 ¼ pt.) per lb. of the bait mix. Similar formulations were used in Mauritius (Anon. 1942), Sumatra (Feij 1940), and elsewhere. The relatively unimportant catches made by this bait (van Weel 1949) suggested the need for a stronger formulation. The percentage of metaldehyde was increased to 5–10 per cent by Pangga in the Philippines (1949) with "very satisfactory" results. In the same area, Cendaña (*in litt.* Feb. 12, 1952) used a 10 per cent mixture on slices of ripe papaya and managed to produce a kill of 33,863 giant snails with two kilos of bait. He complains, however, that the bait lasted only about three days; but that is not a new problem. Dr. J. J. H. Szent-Ivany reported at the Ninth Pacific Science Congress that Dr. Bridgeland of New Britain successfully protracted the effectiveness of metaldehyde by mixing it with paraffin oil.

Corbett (1938) attempted to protect metaldehyde from rain and to keep it from poisoning poultry by putting it in impractical cigarette-can cages. Dias and Thamotheram (1939) suggested the use of a hood of corrugated iron. A shield of bamboo has been suggested by others (Beeley 1938*a*, Anon. 1942). Inverted wooden blasting powder boxes were used successfully in Guam (Peterson 1957). R. C. L. Notley (*in litt.* Nov. 17, 1951) met the problem in Ceylon by putting the metaldehyde-bran bait on the underside of curved tiles. Elsewhere in Ceylon the author observed the use of metaldehyde bait shields made by interlacing two large leaves, petiole-to-midrib. When the potency of the bait had been spent, however, these shields afforded excellent sanctuary from the killing sun. In some cases, the vast accumulation of snail excreta vouched for the fact that the leaves had provided effective shelter for a considerable period of time.

To get a more durable bait, Altson (1950*b*) mixed metaldehyde with cement and lime to form a so-called "brick bait." This he found durable but insufficiently attractive. The addition of rice bran as a fourth ingredient, however, produced a bait which was attractive both to snails and slugs and was clearly superior to the cement-lime-calcium arsenate "brick bait" in areas where lime was naturally abundant. Numerous experiments showed that increasing the bran increased the attractiveness of the bait; and increasing the cement increased its durability. It was suggested that metaldehyde, lime, rice bran, and cement be compounded by weight in the ratio of 1:2:6:6. Since rice husk is cheaper, three parts of it can be substituted for two parts of the rice bran and the cement can then be reduced by one part.

A number of modifications of the basic metaldehyde-bran bait have been made by various investigators. Powdered $CaCO_3$ has been used in place of, or in addition to, the bran with greater success in areas where the soil is low in lime (Notley *loc. cit.*). Banana peelings (Pangga 1949) and papaya fruits (Cendaña *in litt.* Feb. 12, 1952) similarly have been used as attractants with metaldehyde. Cutting the cost of the bait by substituting sawdust for the bran produced a less attractive bait, but one that was effective for 8–10 weeks (G. S. Dun *in litt.* April 17, 1950).

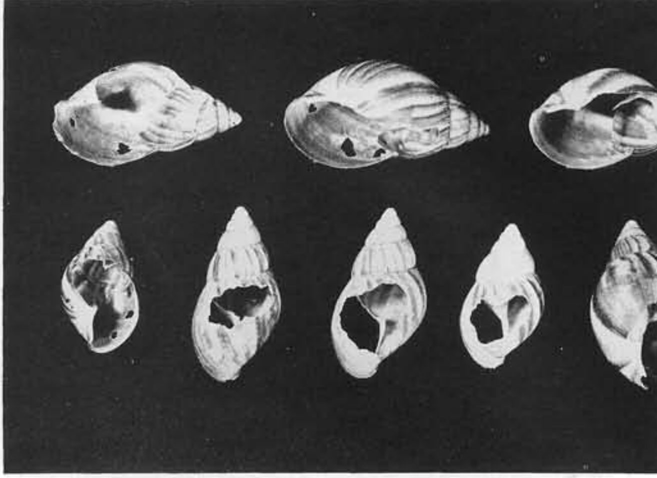
The use of the straight metaldehyde in either the pellet or powdered form has been advocated by many (FitzGerald 1947, Townes 1946, *etc.*); this is not only more expensive than the mixed baits, but it is actually less effective. Speyer's conclusions (1954) bear out this assumption. If it is effective at all, the only thing that can be said in its favor is that it does not require costly preparation.

To increase the spreading effect as a contact poison, Jary (1939) mixed the powdered metaldehyde with sand and obtained impressive results. In an effort to meet a similar need in protecting orchids with a thin cover of metaldehyde, Alicata (1950) used a 1 per cent aqueous suspension spray with a far better killing effect than was found with the metaldehyde baits. Blauvelt (1952) emphasized that a 10 per cent metaldehyde dust on orchids killed more slugs by contact than would be attracted to baits. These reports persuaded Jefferson (1952) to make comparative studies of sprays and dusts. He prepared his wettable powder by grinding the metaldehyde with a silicate clay in a hammer mill. The 66.6 per cent metaldehyde-clay concentrate powder, in turn, was mixed with pyrophyllite to produce metaldehyde "dusts" of varying concentrations. After considerable experimentation, he found that a 15 per cent dust with a coverage of 1–2 lb. per 1,000 sq. ft. was most economical and more effective than heavier coverages of lower per cent dusts. The dust should be applied at night and in at least three applications at 7–10 day intervals. A 10 per cent dust is reported to be effective in contact killing not only the adult slug,

FIG. 4.—In many parts of central west Africa, giant snails of several species provide the greatest single source of protein in the diet of humans. The snails may be purchased in the market place (*left*) and either prepared for immediate consumption or removed from the shell, put on wooden skewers, smoked, dried, and stored for consumption during the dry season (*right*). (Photos courtesy of I.F.A.N.: A. Cocheteux, Ivory Coast.)

FIG. 5.—The trunk of the jak fruit tree *Artocarpus heterophyllus* provides refuge for the giant African snails during the day and its sweet bark supplies one of the choicest food items during the night. Freshly rasped areas appear low on the trunk.

FIG. 6.—Shells showing characteristic damage by the jungle crow (*Centropus chlororhynchus*) in Ceylon. This type of damage is in contrast to the destruction of the apical whorls by the bandicoot and the flecking-off of the body whorl by the rat, the hermit crab, and the coconut crab.



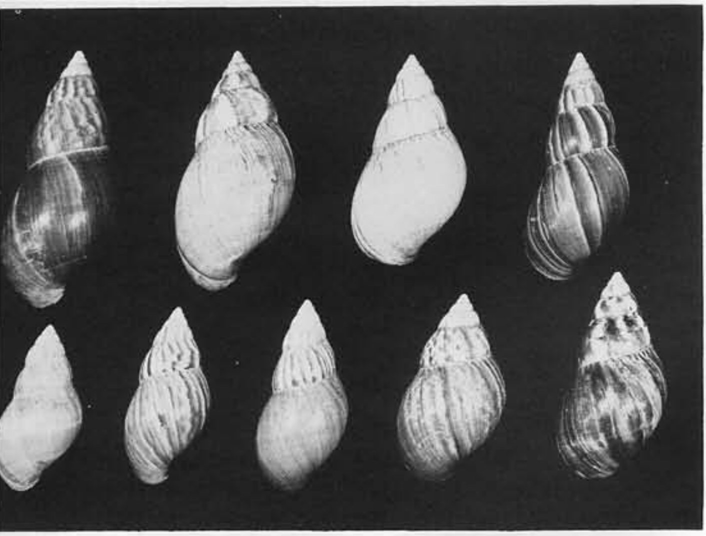
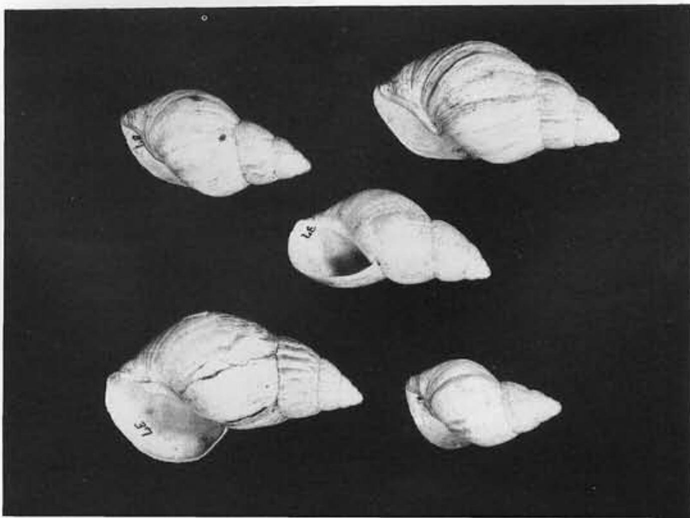


FIG. 7.—Variability in *Achatina fulica* Bowdich. From upper left to lower right, the specimens were collected in: Oahu, Hawaii (*ca.* 140 mm.); Mombasa, Kenya; Saipan, Mariana Is.; Pallekelle, Ceylon; Koror, Palau Is.; Agiguan, Mariana Is.; Saipan; Luzon, Philippine Is.; and Calcutta, India.

FIG. 8.—Approximately one out of four specimens of the Army Hill population of the giant African snail in Saipan in 1949 were of this "bent-nose" type with an arcuate axis, highly irregular lower whorls, heavy lamellate deposition of calcareous material on the columella, and an almost complete lack of shell pattern and periostracum. Genetics rather than malnutrition or disease appears to hold the explanation.



D. reticulatum, but the eggs as well (Lange and Sciaroni 1952). According to Jefferson, 10–15 per cent metaldehyde dusts were not satisfactory for *H. aspersa* and *Oxychilus cellarius.* Dusts composed entirely of 42–50 per cent wettable powder, however, were lethal to the snails, but obviously were economically unfeasible. A spray consisting of 6 lb. of 50 per cent wettable powder to 100 gal. of water and distributed at the rate of 1 gal. per 30–35 sq. ft. proved lethal to snails. It was recommended, however, that in addition to this spray metaldehyde baits be used as a supplementary measure. Jefferson pointed out that the sprays have a disadvantage in that they are more costly to prepare and more difficult to apply than the dusts. Doucette (1954) determined that a 15 per cent dust, in the absence of rain, was effective for a maximum of only 6–7 days, in contrast to a 2 per cent pellet bait which was effective for 12 days. He therefore concluded that the baits should be used on fallow ground; but in gardens, where the bait would be in competition with green foliage, metaldehyde dusts should be applied in bands in such a way that they would have to be crossed to get to the plants. In contrast to Jefferson's spray application equivalent to *ca.* 40 lb. of metaldehyde per acre, and more in keeping with the findings of Cragg and Vincent, Moreton (1953) recommended a spray application equivalent to 2.5 lb. of metaldehyde per acre, with the comment that increasing it to 5 lb. per acre brought in only slightly higher catches. But even at the lower amount, he contrasted it with the 0.5–0.75 lb. of metaldehyde per acre required in the distribution of "standard bran baits" and pointed out the greater cost must be weighed against the potentially greater effectiveness of a contact poison as compared with a stomach poison. In quite the other direction, Leoni (1953*a, b*) recommended an impractical and admittedly expensive spray containing linseed oil and whole milk in addition to an excessively high percentage of metaldehyde.

Jefferson determined that wettable powders and dusts of metaldehyde deteriorated rapidly and therefore must be prepared only a short time before use. Cragg and Vincent and Moreton demonstrated experimentally that metaldehyde sprays and dusts after application lose their effectiveness within a very few days; hence, treatment must be repeated periodically. These findings are in sharp contrast to the report of Blowers (1954) wherein he states, without presentation of experimental evidence, that a recently released commercial suspension of metaldehyde will leave a semipersistent coating of metaldehyde "sufficient . . . for many weeks."

Similarly, Karlin and Naegele (1958) found a 15 per cent metaldehyde dust superior to a 20 per cent spray in that it remained effective for a period of three weeks in killing slugs.

The relatively evanescent property of metaldehyde in sprays and dusts, and the consequent need for repeated frequent application, sharpen just that much more the contrast to the proportionately small amount of metaldehyde required when standard baits are used. The experimental work with metaldehyde teaches us that, in the final analysis, the most economical type of application can be determined only when the density of the snail population, relative humidity, temperature, sunlight, available shade, extremes in the diurnal-nocturnal temperature cycle, and other environmental conditions are known or can be discovered.

At the present time, only in the Hawaiian Islands have metaldehyde dusts and sprays been used against *A. fulica*. Although it has been used in strength equal to that of the dust, the spray has given much better results (Weber 1954). Regarding the spray, Thistle (1953*b*, 1954*b*) reports that "while transitory in effect, it is useful . . . where arsenical or other highly toxic sprays cannot be used."

Lange and MacLeod (1941) reported that the following aldehydes mixed with bran in 3 per cent strength were not observably attractive to slugs and snails: acetaldehyde, paraldehyde, hexaldehyde, butyraldehyde, propionaldehyde, valeraldehyde, and heptaldehyde. In carefully controlled experiments with *D. reticulatum*, Cragg and Vincent (1952) found no contact, haemal, or stomach poison effect in acetaldehyde and paraldehyde. Leoni (1953*a*, *b*) submitted corroborative evidence.

Methyl Bromide: Higher and higher concentrations of this deadly gas have had to be used by the California Bureau of Plant Quarantine in order to insure a 100 per cent kill of the giant snails in the cargoes of ships coming in from infested areas (A. P. Messenger *in litt.* Jan. 4, 1950). There still is much uncertainty as to the amount actually needed under a given set of conditions.

Naphthalene: Uncertain and variable results were obtained by Massee (1928) when this chemical was used in an attempt to control slugs. Miles *et al.* (1931) found it neither lethal nor appreciably repellent to the slug *M. sowerbii*. In contrast, out of a number of chemicals tested Dustan (1927) recommended naphthalene flakes as the best general repellent. To a large extent, his recommendation was based on the fact that naphthalene flakes are resistant to the leaching action of rain.

Parathion: A 2 per cent parathion and 5 per cent metaldehyde contact dust was found to be very effective in controlling slugs (Lange and Sciaroni 1952). There are suggestions of a synergistic action in this combination. Karlin and Naegele (1958) branded parathion as "unreliable" and warned of its extreme toxicity. Unimpressive results were obtained in field tests on *H. aspersa* (Pappas and Carman 1955).

Paris Green: Lovett and Black (1920), in their experiments with *D. reticulatum,* showed that Paris green had a definite repellent effect upon this slug and that it was eaten only under stress; but even though it was eaten sparingly, it was usually fatal. Apparently the recommendations of Hodson (1925) were incorporated in the slug bait formula of Douence (1929), viz. 1 lb. of Paris green, 20 lb. of bran, and sufficient water to make a "damp" bait. This was reported to be sufficient for an acre. The 1:30 formulation of Miles *et al.* (1931) gave uncertain results against *M. sowerbii.* Thomas (1944) tried a 1:28 formulation as a slug bait and produced "20–50 per cent kills." Cameron (1939) added to a 1:25 formulation ½ pt. of molasses, instead of "a little sugar" as recommended by Hodson; but he obtained less good results than he did with metaldehyde baits. Plaster of Paris, bran, and Paris green "biscuits" were made by Thomas (1948) but they did not prove effective in controlling slugs. Pangga (1949) found Paris green "ineffective" against *A. fulica* though he did not indicate the nature of his experiments.

Phenol: Along with a number of other suggestions for slug control in Australia, French (1906) recommended the use of "carbolized sawdust." Ewart (1910) claimed an improvement in this repellent by moistening a bucket of sawdust with a solution made up of 1–2 cups of "phenyle" in 10–20 large cups of water. Severe burning of foliage by "crude carbolic acid" was demonstrated in the experiments of Lovett and Black (1920) and it was therefore considered to be of little practical use in the control of slugs. A 1:500 aqueous solution was reported by Miles *et al.* (1931) to be effective in controlling *M. sowerbii.* The formulation of Ewart was suggested by Green (1911*a*) as a possible control measure for *A. fulica.*

Potassium Permanganate: The experimental use of this chemical as a contact poison for slugs was claimed by Hall (1932) to be "excellent." Miles *et al.* (1931) found it not lethal to the slug *M. sowerbii.*

Potassium Cyanide: This exceedingly poisonous chemical was found by Lovett and Black (1920) to darken various baits and render them unattractive to slugs and snails.

Pyrethrum: A mixture of this insecticide and bran (Thomas 1948) was shown to be attractive to slugs (probably largely if not entirely because of the bran), but no kills were produced. Pangga (1949) found pyrethrum toxic to young *A. fulica* but not to the adults.

Repellents

Although a great many chemicals and compounds, including several listed here under separate headings, are repellent in nature, by far the majority produce only transitory irritant effect, or effects which last only while the snail or slug remains in contact with them. In cases where the irritant effect is so severe that death is produced, the substance is more correctly referred to as a contact poison (*q.v.*). From this, it is obvious that the difference between a repellent and a contact poison may be simply a matter of different concentration of one and the same chemical. And, further, repellents may be considered most effective when they are also contact poisons.

Lovett and Black (190) conducted the first extensive experiments to find an efficacious slug repellent. Certain combinations of carbolic acid, sulphur, gasoline, lime, and sodium hydroxide were found to be temporarily repellent but the damage to foliage made them impractical. Combinations of hellebore (*Veratrum*), nicotine sulphate, sulphur, lime, and tobacco dust similarly had a temporary repellent effect, but it was lost or greatly reduced with rain. In their early experiments, nicotine sulphate solution (1:800 aqueous) and air slaked lime and tobacco dust (5:1 by weight) were recommended as "excellent" repellents. Later, Paris green, copper sulphate, and especially Bordeaux mixture (*q.v.*) were shown to be the best repellents. Unidentified slugs were exposed to eleven different substances by Dustan (1927) in an effort to find a good chemical repellent. He found that naphthalene flakes, because of their resistance to heavy rains, proved to be the best of the lot. In order of decreasing importance, he recommended four others, viz., sodium fluoride, magnesium fluosilicate, sodium chloride, and creolin (5 per cent aqueous). Tanglefoot, hydrated lime, fish oil emulsion, flowers of sulphur, tobacco dust, and calcium fluosilicate were insufficiently repellent to warrant further consideration. Miles *et al.* (1931) ran other extensive tests and found that aluminum sulphate, ammonium chloride with phenol, ammonium sulphate, copper sulphate, drained creosote salts, potassium permanganate, and sodium carbonate were definitely repellent to the slug *M. sowerbii.* Phenol in a 1:500 aqueous solution was particularly good. The best repellents were stated to be creosote in powdered chalk and 1:500–1:1000 aqueous solutions of mercuric chloride. Chlorcresylic acid in chalk, naphthalene, and nitrate of soda were shown to have little or no effect as repellents. Tryon (1899) recommended the use of tobacco waste as a repellent and contact poison in the control of vaginulid slugs. Ferrous sulphate is reported by Basinger (1927) to be repellent to *T. pisana.* A solution of rubber in crude oil effectively repels *A. fulica* in Malaya (Altson 1950*a*). Trenches sprayed with crude oil were completely effective in repelling the giant snail in Guam (Peterson 1957). In Ceylon this snail is reportedly repelled when the aromatic Khas Khas (*Vetiveria zizanoides*) is used. Several authors (e.g., Hall 1932) have recommended the use of sheets of zinc as repellent barriers. Others suggested using plain sawdust (e.g., "R.B." 1952). An early investigator (Miège 1906) recommended hog bristles!

Soap solution: Soap solution has proved to be only moderately promising in controlling slugs (Lovett and Black 1920). Similar results with *A. fulica* have been reported by Pangga (1949).

Sodium Chloride: Common table salt has long been a household method of killing slugs and snails. Although Anderson and Taylor (1926) used it against slugs in field tests without satisfactory results, Dustan (1927) and Vandenberg (1929) found it effective. Latif 1933*a*) used it as a repellent to protect potted orchid plants from the giant African snail. Hall (1932) recommended the use of an aqueous solution rather than the dry salt; but Pangga (1949) was able to produce kills with the solution in only the young specimens of *A. fulica.* In Guam, salt water sprays proved practical only in areas where there would be incurred no damage to the soil, for example, in beach zones and along roadways (Peterson 1957).

Sodium Dinitro-orthocresylate: G. S. Dun (*in litt.* Nov. 25, 1949) quite accidentally discovered that this weed killer produced a contact killing effect on *A. fulica* in New Britain. This observation warrants investigation.

Sodium Fluoride: The slug *D. reticulatum* was shown to do very little feeding on bait poisoned with this chemical (Lovett and Black 1920). Dustan (1927) and MacDougall (1931) were able to obtain good slug kills with it; but MacDougall did not recommend its use because of the burning effect it had upon plant foliage. Hodson (1924) had earlier come to the same conclusion.

Sodium Fluosilicate: In the revised edition of the USDA Farmers

Bulletin No. 1895, it is recommended that metaldehyde baits be fortified with either this chemical or calcium arsenate.

Soot: This has been recommended for controlling slugs and snails, but with the warning that unless carefully applied to plants, there may be damage (Anon. 1930). Earlier, Durham (1920) found that even when it was combined with lime, it was of little use in killing slugs.

STOMACH POISONS, MISCELLANEOUS

Baits containing diethylparanitrophenyl thiophosphate (i.e., Rhodiatox) and dinitro-o-cyclohexylphenol were found by Pereira and Gonçalves (1949) to be less effective than metaldehyde and therefore were not recommended. Levy (1938) patented a bait containing rotenone; but there is no evidence in support of its questionable effectiveness.

Strychnine Sulphate: In spite of the fact that this was readily eaten by slugs, it did not have a killing effect (Lovett and Black 1920).

Sulphocyanides: Although some of these were very lethal to the slug *M. sowerbii,* they were so deliquescent that they were considered useless in any large scale operation (Miles *et al.* 1931).

Tartar Emetic (potassium antimonyl tartrate): Lewis and LaFollette (1942*a*) report high kills of *H. aspersa* with a spray of tartar emetic. Persing (1944*a*) states that such sprays "show exceptional promise" especially as an emergency measure to stop immediately damage to citrus trees and fruits. He recommends adding 2 lb. of tartar emetic and 4 lb. of white or brown sugar to 100 gal. of water and applying it with a boom gun or boom sprayer at the rate of 3–4 gal. per orange tree. A 6:12:100 ratio is used if the solution is applied with a spray-duster.

Warfarin: In Guam, achatinas consumed with apparent complete impunity rat bait containing warfarin (Peterson 1957).

Whitewash, Poisoned: The lack of natural limestone in Ceylon encourages the giant snails to remove the whitewash from the houses. This has suggested the use of bags of poisoned whitewash as a control measure (Connolly 1931). Because some parts of Java are equally poor in limestone deposits, Benthem Jutting (1934) has recommended the same type of control.

Chemical Control—an Evaluation Any attempt to evaluate on a comparative basis the various chemicals and compounds listed above is frustrated from the outset because there has been reported in the literature too little of an exact nature upon which to base scientifically a comparison of any great extent. Although a number of the experiments with molluscicides have been adequately controlled, the conditions under which they have been conducted have been so variable that their results are not reducible to any sort of common denominator. For example, the animals used in the various experiments have been different species of slugs and snails, with varying tolerances to the different molluscicides. This is complicated by the general belief that there is a fundamental marked difference between slugs and snails in their capacities to withstand toxic effects. Therefore merely because a certain formulation is shown to be effective in controlling slugs, it does not necessarily follow that it will be equally effective in controlling the giant African snail. On the other hand, many of the reports in the literature are inadequately supported by factual detail. A case in point is the work of Pangga (1949) on *A. fulica.* Without giving a single detail as to the nature of many of his experiments, he simply states that certain chemicals have little or no effect upon this giant snail. In other cases in the literature, there is very strong evidence of insufficient or no controls in the experimentation. Such, of course, are fruitful grounds for biased or specious conclusions. So little is known about the normal physiology of terrestrial gastropods that to a great extent, the toxicological effects of the various molluscicides are simply not understood. But in spite of these drawbacks, much of a positive nature can quite safely be concluded from the collected and collated data.

First of all, it is more than apparent that a poison, even approaching the ideal for the giant African snail, has not yet been found. "Repellents" as such, by their very nature, are of the most limited value and they therefore can almost completely be dismissed at this point. They are of use only on a small scale; for example, to protect individual plants or small garden plots. They therefore are to be considered more in terms of a protective measure rather than of a control per se. In contrast, "poison baits" have been put to considerable use in control programs and they still continue to provide much promise of help as new combinations are being formulated. The requirements of a good poison bait, however, are very great and unfortunately in practice they are sometimes basically antagonistic to each other. Ideally, a poison bait should contain a powerful attractant and toxicant; it should consist largely of a readily available, inexpensive diluent; it should have a high degree of stability; and its application should provide the very minimum of difficulty.

With the appearance of the comprehensive work of Kieckebusch (1953), there no longer can be justifiable doubt about the existence of a very keen olfactory sense in snails. But finding a suitable attractant, which will not be neutralized or made impracticable by some local or environmental factor, is anything but a simple problem. For example, lime is generally considered a good snail attractant, but in areas where there is a natural great abundance of calcareous material, it is very much less effective. Lewis and LaFollette (1941, 1942*a*, *b*) showed that substituting fresh orange pulp for bran as the attractant-diluent in arsenical baits used to control *H. aspersa* in California citrus groves not only appreciably increased the effectiveness, but reduced the cost 75 per cent. An attractant of this sort however has the disadvantages of being obtainable in only a very restricted area and of spoiling quite rapidly under usual field conditions (Persing 1944*a*). Sugar similarly increases the attractiveness of baits but it hastens their spoilage (Thomas 1948). Bran itself quickly loses its attractiveness under conditions of high humidity. Metaldehyde is an attractant, but if it is used in excess, it may actually serve to "protect" the snail from the poison bait by interfering with the amount it can consume. The discovery of a positive anemotaxis in *A. fulica* (Chamberlin 1952*a, b*) suggests that the attractant qualities of a bait can be taken fullest advantage of if the bait is placed upwind to the greatest concentration of the snails.

Obtaining a suitable toxicant presents equally difficult problems. Some of them chemically alter the other constituents of the bait. Others have been demonstrated to be highly toxic to snails, but they are of such a nature that they are seldom consumed and hence they act more like repellents than toxicants. To find a toxicant which will be effective under all conditions of weather is even more difficult. Quite naturally, optimum concentration of the chemical is of prime importance and it is therefore necessary to take into consideration the dilution factor of environmental moisture. Some toxicants produce the greatest total kills under warm, moist conditions; but such conditions favor rapid spoilage of the bait—especially through the development of mold. Other quite effective toxicants when excessively diluted, become mere irritants from which the snails may survive by throwing off a great deal of slime. This is especially the case during rains, which may actually wash the toxicant completely away in a few minutes' time. On the other hand, the supplemental killing effect of the sun, through desiccation, upon individuals stunned by the toxicant may be rather badly offset by the fact that in the meantime the bait has dried out and become ineffective. Even though some baits, such as those containing metaldehyde, can be rejuvenated after dehydration simply by remoistening, the mechanics of the process on a large scale would become a considerable item both in time and cost. It is an obvious fact that tropical conditions in general are basically antagonistic to any measure of stability in snail baits. Providing some sort of shelter for the bait, no mater how simple, inevitably is impractical except on the smallest scale. Moreover, shelter for the bait often means shelter for the snail; thus damage to plants may actually be increased through the unwitting provision of an attractive shelter from the killing action of the sun, persisting long after the poison has lost its effectiveness. The use of cement in baits has provided a very welcome element of stability; but this has its shortcomings in making the bait less attractive and in some cases less toxic. In general, oil base baits hold up better under moist conditions.

In the final analysis, the practicability of application of a specific bait or toxicant is the decisive factor. No matter how effective a snail poison is, if it requires anything more than a minimal amount of labor in its application, if it is expensive in the least, if it provides dangers to the lives of other animals, if it produces appreciable scorching of plant foliage, or if it is difficult to prepare, its use most definitely will be very limited. Even if each of these problems is adequately met, the actual effectiveness of a molluscicide is influenced to a considerable extent by such environmental factors as humidity, sunlight, contrast in the temperatures of night and day, rainfall, soil type, terrain, and plant cover. It becomes necessary then to determine optimum conditions under which snail poisons can be used. For example, it would be a senseless waste of time and materials to disseminate a poison, no matter how effective it is, at a period when environmental conditions have forced a majority of the snails into estivation. If under the same conditions, however, local irrigation brought the snails out of estivation, disseminating the poison would be clearly indicated. But the interplay of the various environmental factors can produce strange results. In certain regions in Ceylon, and in the Pallekelle District in particular, there was the strongest evidence that an intensive poisoning campaign (metaldehyde bait put out weekly for eight months) actually brought about an increase of the population of giant snails!

Metaldehyde and calcium arsenate unquestionably are to date the chemicals of choice in attempts to control *A. fulica*. However, there is among investigators no general agreement as to which is the more useful or even whether there is any synergistic factor in their combination. Some (e.g., Lange and MacLeod 1941, Anon. 1949*h*, USBEPQ 1953) indicate that in controlling slugs and snails, metaldehyde-bran baits are more effective, especially under dry conditions, than calcium arsenate-bran baits, and that the addition of calcium arsenate, sodium fluosilicate, or Paris green to a metaldehyde bait increases its effectiveness. Others (e.g., Lewis and LaFollette 1942*a, b;* Persing 1944*a*) insist that, at least as far as the control of *H. aspersa* is concerned, calcium arensate baits are better than the metaldehyde baits and that, except during hot weather, the greater cost of combining the two chemicals in a bait cannot be justified. Apropos of this general subject, it is unfortunate that Altson (1950*b*) did not extend his experimentations to include the addition of calcium arsenate to his "brick baits" of cement, lime, metaldehyde, and rice bran. Thomas (1944) convincingly reports on the superiority of meta-bran baits over Paris green–bran baits. In screening thirty-two possible molluscicides, including the promising Isolan, Pappas and Carman (1955) found none superior to the commercial pelleted bran bait containing 6.75 per cent calcium arsenate and 1.5 per cent metaldehyde. Peterson (1957) used this formulation in Guam and makes the following report regarding its action on the giant African snail: "Following ingestion of the bait, snails usually became paralyzed within 10 to 15 minutes and died within 30 minutes to 1 hour. It was found that migrating snails killed by the bait and left on the ground would be partially eaten by other snails the following night and additional snails would be killed."

Recent extensive correspondence with investigators in the field has revealed the fact that a rice bran–metaldehyde bait is still considered in most areas infested with *A. fulica* to be the only practicable chemical control method. According to Pangga (1949), calcium arsenate–rice bran bait was much less effective on this species than was the meta-bran bait. In the Hawaiian infestations, however, the metaldehyde baits were found less practical and in the long run more expensive than the calcium arsenate–slaked lime–cement mixture. Broadcasting straight metaldehyde in the form of pellets is a simple, expensive, and relatively much less effective method of controlling snails, and its use in this form has quite understandably been discontinued in many areas. Disseminating metaldehyde in sprays and dusts similarly is costly, but very much more effective; the unfortunately transient nature of the effectiveness of such applications, however, increases the labor and cost factors far beyond practicability in most cases.

No matter what chemicals or baits are used, invariably there are disadvantages and even dangers involved which must be taken into consideration and which must condition their use. Of prime concern, of course, is the possibility of endangering the lives of humans, livestock, and poultry (cf. Douence 1929). This is particularly the case when the relatively effective sprays of sodium arsenite or corrosive sublimate are used. The indiscriminate use especially of arsenicals and metaldehyde introduces very real problems in this direction. And although the element of danger in the use of arsenicals is fairly well understood and appreciated, the same probably cannot be said for metaldehyde. Within months after the initiation of its use as a molluscicide, J. P. Hudson (1937) announced with obvious concern that birds were seen to be removing dead slugs and snails from metaldehyde baits. A few weeks later, the fears he expressed were confirmed in the report of R. H. Hudson (1937) who stated that a blackbird and a starling, after feeding on metaldehyde bait, soon "fluttered about screaming in obvious agony, and . . . died about half-an-hour later. . . ." To obviate this danger, Carbett (1938) suggested the construction of special bait cages that would permit the entry of snails but would exclude fowl. In an attempt to determine the poisonous nature of metaldehyde to pets, Shewell-Cooper (1938) checked with the Royal Society for the Prevention of Cruelty to Animals and obtained a significant report, a part of which follows: ". . . in several instances dogs have died from eating meta, which was apparently put down to destroy slugs. . . . In one case we had an analysis made of a dog . . . and the result of the analysis clearly showed that the dog died from consuming meta." The following year, Jary indorsed the stand of exercising great caution in using metaldehyde and introduced the suggestion that it might be harmful to earthworms—a point which seems to have been ignored since then. That same year, Lewis *et al.*, echoing the earlier warnings of Gimingham and Newton (1937), presented the medical history of a thoroughly convincing case of death in a child from metaldehyde poisoning. According to their report, accidental death of other children and attempted suicides of adults are on record. They warn, without presentation of evidence, that ". . . the method of mixing it with bran has been responsible for the innocent slaughter of many of our wild birds." In direct contrast to these reports, Cameron (1939) fed two chickens for four weeks on a total of two pounds of a 1:50 meta-bran mixture along with their regular feed. Even though it is believed that this amount is in excess of what they would be picking up under normal field conditions, the chickens remained unaffected. Fernando (1952) similarly minimized the dangers of metaldehyde by stating: ". . . dogs, cats and poultry will sometimes taste the bait and reject it without ill effects." Among many other toxicants used against invertebrates, Tilemans and Dormal (1952) list metaldehyde as a nerve poison with an LD_{50} of 170–200 mg/kg for man and 250 mg/kg for dogs. For intoxication, the symptoms of which they describe, they recommend vomitives and an antispasmodic of chloral chlorhydrate. When either metaldehyde sprays or dusts are used, there apparently is no phyticidal effect even on such delicate plants as orchids (Jefferson 1952, Moreton 1953).

If bait containing toxic agents is broadcast instead of being placed in heaps, any possible hazard is considerably reduced—but unfortunately so is the efficacy of the bait. This leaves still unaltered the problem of soil contamination; for example, the prolonged use of arsenicals eventually interferes with normal agricultural practices in that the accumulation in the soil builds up beyond the tolerance point of some arsenic-sensitive crop plants (Pierce 1931). In areas subjected to periods of drought, there is danger of a surface concentration of molluscicides through the siphon action of deeper soil moisture being drawn up by capillarity to replace evaporated surface moisture. If copper exists as a contaminant in the arsenical, subsequent insecticidal fumigation of the plants with cyanide may produce severe injury to the foliage (Gammon 1943). In Hawaii, it was not the poisonous nature of the calcium arsenate–cement–lime mixture to which some of the complaints were directed; it was the fact that stones, painted with this mixture, were broadcast in grassy areas where they caused damage to lawnmowers!

Unfortunately, the promising tartar emetic sprays henceforth will be used in the United States only on a very limited basis because of the discontinuance of the large scale commercial production of potassium antimonyl tartrate.

Copper sulphate has seemed to be inordinately popular in the recommendations of many who have been faced with the control of the giant African snail. To a fair extent, this is unfortunate. The frequent rains in the tropics quickly wash away this chemical and require the addition of more. Its continued use not only builds up an abnormally high concentration of the copper ion, but it very appreciably increases the acidity of the soil. In the strongly basic soils of the coralline islands, this change in pH might be an advantage; on the other hand, it might be quite deleterious to crops which are sensitive to acid soils. Miles *et al.* (1931) have suggested the concurrent addition of an equal quantity of lime to offset this acidifying effect. This brings up the point that the molluscicidal use of lime will conversely alkalinize the soil. This directly favors the survival of the snails but not certain crops, such as tea, which demand an acid soil. Plants which have been injured by the feeding of snails absorb $CuSO_4$

rapidly at the wound site and die. But even healthy plants may be burned severely by this chemical if it is applied in too high a concentration. Pangga's experiments (1949) suggest that there has been an overemphasis of the use of $CuSO_4$ against *A. fulica.*

The value of ashes has similarly been overrated. For one thing, except under the most unusual conditions, ashes in any quantity will not be found in the tropics. When it becomes soaked with rain, it is useless and will need replacing. Besides, the washing of ashes into the soil will alkalinize it with the resultant disadvantages indicated above.

Of the poison gases used in fumigation of cargoes infested with the giant snail, ethylene dibromide seems to hold much greater promise than methyl bromide, hydrocyanic acid, or carbon disulphide. Accurate determination of adequate concentration of any of these gases to insure a 100 per cent kill has yet to be made.

Some of the newer insecticides may be found, after much more extensive experimentation, to possess sufficiently great molluscicidal properties to be of use in giant snail control programs; but the results so far have been neither spectacular nor promising. For example, the work of Pappas and Carman (1955) appears to have quite convincingly eliminated from further serious consideration, except for some possible synergistic effect, such common insecticides as aldrin, chlordane, DDT, dieldrin, endrin, isodrin, malathion, and parathion. W. H. Lange, of the University of California at Davis, however, believes that at elevated temperatures, some of these insecticides become effective. He is currently conducting tests which promise to bring to light new organic toxicants of unprecedented molluscicidal properties.