Physical Methods of Pest Control*

Walter M. Carleton and L. A. Liljedahl

Agricultural Engineering Research Division, Agricultural Research Service, Department of Agriculture, Beltsville, Md. **

Introduction

Pests will be defined in this paper as organisms, such as insects, weeds, parasitic plants, and animals and viruses, which cause economic losses in agriculture, or which are considered noxious to man. Pests, like all living things, live in a total environment which can be roughly partitioned into physical, chemical, and biological environments. The pest responds to changes in these environments and all three environments can be manipulated to control the pest. Which of these component environments or which combination of them we choose to manipulate for pest control, will depend to some extent upon the times, because technical knowledge of the effect of these environments on the pest grows somewhat sporadically. Also, the economics of manipulating one or another environment changes, frequently due to technical developments quite outside the field of pest control.

Our earliest methods of pest control were invariably physical. They did not require sophisticated technology, the effects were immediate, and they were conclusive. House flies were controlled, poorly, we think now, by fly swatters and sticky paper. Weeds were pulled up and left to die, or cultivated with the same results. Our whole present pattern of agriculture, that of growing many crops which are susceptible to weed infestation in rows in order that they can be cultivated, dates back to the discovery that row cropping practice permitted a more methodical type of physical pest control.

As our knowledge of chemistry and biology has increased, we have become able also to manipulate the chemical and biological environment of pests. It has indeed frequently so engaged our attention that the physical environment, and its possible manipulation, are now often neglected. In fact new and more glamorous ways of accomplishing these objectives are often mistaken for cure-alls, and physical methods, instead of continuing to supplement new practices, are frequently abandoned.

It would appear axiomatic that research on all phases of pest control will be most effective when there is well organized cooperation among the scientific disciplines which study the chemical, physical, and biological environment of the pest, wherever and whenever the situation and resources permit (9). The actual control methods which are practiced certainly should also include all three phases of the pest environment for best control of the pest. It seems likely in fact, that some mix of various levels of all three types of pest control would result in the method which would produce the maximum control for a given cost. This approach, termed integrated control by some, is supported by the bulk of ex-

---

* Presented by Dr. Carleton on December 29, 1966, as part of a symposium entitled, "Scientific Aspects of Pest Control," held at the 133rd meeting of the American Association for the Advancement of Science in Washington, D. C. The symposium was sponsored jointly by AAAS Section C (Chemistry) and Section F (Zoological Sciences).

** Dr. Carleton is director of the Agricultural Engineering Research Division, and Dr. Liljedahl is chief of the Division's Crop Production Engineering Reesarch Branch.

perience found in systems analysis in a wide variety of economic problems, and supported by analogy with good medical practice as well. The vast majority of recommended therapies for human diseases and disorders include recommendations for improving *all* phases of the patient's environment. One does not reasonably expect to be completely cured by therapeutic chemicals while ignoring the effects of undesirable physical and biological environments of the patient.

Finally, if physical control methods are not considered, we risk the possibility of ignoring the resources of a highly developed technology. Study of the physical sciences underwent a major expansion possibly 50 years before similar expansions of chemistry and biology. We thus have a large number of individuals, namely engineers of every label, who have had years of experience in exploiting physical science for practical benefit.

What is the significance of an integrated pest control program? It means that, in general, the day is over when a scientist can study the effect of a physical or chemical pest control method, whether it be on an insect, a pathogen, or a weed, without continuous consultation with engineers or physical scientists about the physical problems involved (23). The result is going to be more complicated research. The research is also going to be slower and more expensive. But the results we will get will be worth it.

Mechanical Control

We indicated earlier that methodical mechanical control was once the foundation of plant husbandry and responsible for many of our present cropping practices. In well structured soils it is likely that herbicides can be substituted for most tillage operations. Total reliance upon chemical control, however, encourages buildup of weeds which are resistant. Use of some mechanical control will greatly slow this buildup of resistant species. Experience shows also that only about three out of four years have the climatic conditions, such as rainfall pattern, soil temperature pattern, etc., needed to make herbicides fully effective (19). In soybeans, yield reduction from heavy stands of pigweed or giant foxtail may average nearly 40 percent for corn and 55 percent for soybeans (18, 21, 25). The use of mechanical control thus serves as an insurance against losses of this magnitude if the chemical treatments fail. Recent surveys indicate that more than 98 percent of the total cultivated crop land in Illinois is still given shovel or sweep cultivation each year, and much of the area is tilled more than once (16).

Ohio biologists (32) and others are concerned about the effects of no tillage operations on buildup of diseases and insect pests. In Texas and Nebraska, research revealed (33) that herbicides were most useful for controlling weeds in crops with high plant populations and with narrow row spacings where cultivation was not practical. In Nebraska (34), the present limitations of chemical fallow are erratic weed control, high herbicide cost, and possible loss of crop by herbicide residues.

There are several million acres of once good pasture land in the United States which are now infested with either brush or a non-productive species of grass and weeds. Typically low in acre value of production, the infested areas offer special challenges to engineers and biological scientists in reestablishment of productive grass lands. An attempt is being made to develop economical methods of removing or killing this brush while at the same time establishing suitable stands of grass which are acclimated to this region of low rainfall. Of course this reestablishment must be coupled with good practices of range management, or otherwise the undesirable species will again establish themselves and the range will resume its present low carrying capacity, which may be as little as two or three head of cattle per section of land.

Engineers and agronomists working on the Jornada Range, north of Las Cruces, N.M., are attempting to develop equipment and procedures which will remove the undesirable species, place it in windrows, and at the same time plant desirable grass species below the windrows. It is hoped that the windrows will shade the ground so as to maintain lower soil temperatures and reduce evaporation of the sparse water supply. This should aid in germination of the grass and protect it from soil blowing. Ingenious schemes have been used for removing brush. For example, large ship anchor chains pulled by two large crawler tractors do a fair job. However, complete brush removal leaves the land unprotected and present research relates to utilizing the brush to assist in grass establishment as previously described.

In the states of California and Texas, there are millions of acres of land where the rainfall is higher than in the Jornada Range but where assistance must be given to reestablishment of preferred vegetation. In some cases it is not desirable to completely eliminate the native vegetation which serves as a protection from blowing sands and from erosion by occasional high intensity rains.

Special planting and fertilizing equipment must be designed for these dry and difficult terrains. Not only is the land arid but frequently it is also extremely rough and hilly, causing difficulty in equipment operation. Heavy duty rangeland drills, originally developed by the U. S. Forest Service for use on sagebrush range, have been modified by California workers (17) for seeding trials. Usually the planting procedures take advantage of the use of chemicals to help control weeds in the planted row so that the desirable seed will then have a better chance of taking available moisture from the soil.

Sometimes it is also possible to mechanically control soil-borne diseases. Deep plowing to control a soil-borne disease of mint is a fairly successful practice in Michigan organic soils, and work is presently underway to see if a similar method can be used to control cotton stem rot in Texas.

Mechanical control of insects has been practiced successfully, but, as mentioned earlier, new practices and techniques tend to obscure earlier useful methods. An early means for insect control was the application of plowing to reduce grasshopper infestation. Before the advent of pesticides and pesticide application equipment, deep plowing was recommended for stubble fields. These fields were plowed in strips, with the result that more favorable egg laying conditions existed in the unplowed strips. The latter areas were subsequently plowed to further reduce the grasshopper population. Such methods, even though they are now rarely practiced, at least indicate attempts to carefully observe the physical behavior of the pest and to take advantage of some weak point in this behavior for use in a control measure.

The attempt to find and attack a weak point in the pest's cycle is illustrated by a current study of mechanical control of boll weevils. The weevil lays its egg in the flower bud of the cotton plant, called a "square", which then abscisses and falls to the ground, under the plants, where the insect develops. It is possible that the insect is quite vulnerable at this point in its life cycle, for if the abscissed bud is destroyed or broken open at this point, the insect is killed. A machine to destroy these buds has recently been developed and use of it appears to give good control during the first part of the cotton growing season (6).

An obvious, although insufficiently used, system of control for weeds is to avoid planting weed seeds while planting a desirable crop. It is possible to reduce weed populations considerably by proper seed cleaning. Some seeds are very difficult to separate, but engineers at the USDA seed cleaning laboratory at Corvallis, Oregon, have developed equipment for separating many weed seeds which seem almost identical in shape and physical characteristics to those crop seeds which they are infesting. Some states have rigid laws requiring seeds to meet certain standards of cleanliness before they are sold. In any event, the farmer should exercise due diligence in planting clean seed as one method of pest control. In his own farm operations he can avoid considerable trouble by such practices as cleaning a combine which has been used in a weed-infested field before moving it to a non-infested field.

Temperature Control

Many practices which are considered cultural pest control are in part intended to take advantage of temperature effects on the pest. Use of correct planting dates, and planting patterns which shade the inter-row area, for example, are attempts to restrict weed growth through soil temperature control.

Control of soil and air temperatures in bulk is too costly to attempt at present. It has been known for 15 or 20 years, however, that weeds could be controlled in certain crops by brief exposure of the row area to flame temperatures. Flame weed control, particularly in cotton production, has played an important role in the transition from a nonmechanized to a mechanized production system. Frequently a combination of chemical, mechanical, and flame weed control will give the most consistent results in many crops (12). Several improvements in burner design within recent years have made flame cultivation more efficient and foolproof than in earlier designs. Again, flame weed control is only one of the tools in a completely integrated system of pest control.

In Illinois, during a two-year study, corn exhibited relatively good tolerance to flaming (20). Soybeans were more susceptible to injury by flaming at early growth stages than was corn. The studies suggested that flame cultivation would be less competitive under Illinois conditions where pre-emergence herbicides and conventional cultivation give satisfactory control of weeds. It was suggested that flame cultivation may have more potential in the drier areas where pre-emergence herbicides have been less effective. Small insects ought also to be fairly susceptible to flame, and this method of control has been investigated to a limited extent.

Radiation

Recent engineering work in insect radiation, in cooperation with entomologists, has yielded interesting findings. Of course, insects have been known to respond to lights for many years, but no specific data were available as to the kind of light or intensity which was most or least attractive to insects. Basic research now is being devoted to determining the particular wave length of light to which various insects respond (11, 13, 15). As a result of research, the use of electric light traps probably is now the most effective way of determining insect infestation buildup which, in turn, dictates the need for initiating other control methods. In some cases, it may even be possible to use electric lights as attractants for partial or complete control of certain insects, for example, in cooperative Federal-state research in Indiana for control of cucumber beetles and for control of the tobacco hornworm in one area in North Carolina. Extensive installations of light traps were made by tobacco farmers in Kentucky and North and South Carolina during the 1964 season; a large acreage of cotton was covered during the 1965 season in Texas, and producers of shade-grown tobacco on the Georgia-Florida border are contracting for light traps as part of an integrated control program. Work of this sort may also help to keep down pesticide residues.

Research work by ARS and University

of Nebraska personnel has been devoted to determining the effects of radiation (26), at various frequencies and intensities, on insects in stored grain. Fundamental information is being obtained relative to the effects on both grain and insects, and this research may some day lead to radiation as a part of an overall integrated pest control program.

Entomologists have conducted interesting experiments on the use of aluminum foil around certain garden plants for pest control. For some reason, as yet unknown, the presence of bright aluminum next to the plants seems to repel aphids. It is possible that this repellency is due to reflection of radiation. On some high-value crops, the practice of using aluminum reflectors may also find a place in integrated pest control.

The use of aluminum to repel insects from plants is another example of the increasing need for fundamental research relating to biological reactions of superimposed artificial physical conditions.

Sound

Engineers and entomologists have also extensively investigated the response of insects to various frequencies of sonic and ultrasonic sound, and many studies are currently in progress (27). For instance, an ARS engineer in South Carolina, in cooperation with state personnel, is conducting work to determine the specific frequency and intensity of sound to which a bollworm will respond. Results to date indicate that the insect senses the sound from distances as great as 100 feet. Instrumentation to measure biological reactions of this sort is complicated and expensive and the investigator must have a fairly comprehensive knowledge of both the physical and biological principles included. It is also complicated by the possibility that the insects may respond primarily to modulations of the sound, rather than simple sound itself.

It is interesting to note that research on insect communication may have military applications. It was discovered, for example, that the bat has a built-in sonar system which enables him to locate and catch insects. It has also been discovered by entomologists (7) that some insects can sense the sound made by bats and are thereby able to take evasive action from attack. The sound from the bat, however, is not constant, but consists of short pulses, or chirps. An example of this sort illustrates and restresses the need for fundamental biological information as a basis for the application of advanced physical equipment and principles to solution of biological problems.

Physical Aspects of Biological Control

Entomologists have developed schemes for controlling certain insect populations by superimposing sterilized male insects on the naturally occurring population. These schemes, and other biological control methods, have physical considerations which offer possibilities for improved biological control. For example, certain insects cannot be sterilized by radiation without substantial loss of vigor unless it is done in a rather short and critical interval during development of the pupa. This interval can be differentiated by a change in color of the pupa. Based upon this physical difference, engineers have built equipment which sorts out pupae which are at the proper stage for sterilization. This makes the male sterilization technique possible where it would otherwise be impossible (30).

As another example, our entomology co-workers tell us that if it were possible to separate the male and female insects, the males could be sterilized and the females could be used for other biological control measures. For instance, engineers, in cooperation with entomologists, have developed methods for separating the male and female codling moth pupae based upon slight differences in size. The intention is to irradiate the male population and release it when ready. In the meantime, the female population would be exposed to parasitic wasps. The parasitic wasps multiply in the host pupae and, at the proper time, the pupae can be placed in the natural environment after which the parasitic wasps will assist in control of those insects which have not been controlled by sterilization procedures.

Separation of pupae by sex, maturity, or some other characteristic is often possible based on associated physical differences such as size, shape, density, color, or surface texture, following much the same procedures as engineers use in separating weed seeds from crop seeds.

Physical Aspects of Chemical Pest Control

When chemicals are used to control a pest, it is necessary to physically place the chemical at locations which insure that the pest will contact or ingest it. A chemical which goes anywhere else increases the cost and hazard of its use without any improvement in control. The great biological effectiveness of chemicals has often obscured the fact that the present methods of applying the chemicals, as sprays or dusts, are very inefficient, frequently being of the order of 5 to 15 percent (5). Improving the efficiency of application to say, 50 percent, would permit a three-to-ten fold reduction in the amount of chemical used, with associated reduction in hazards to the environment.

The position of the U.S. Department of Agriculture (31) is to urge that pesticides be used in the smallest effective amounts, applied precisely to the infested areas and no more often than needed for effective control or elimination of the target pest. This implies that greater effort should be made to improve the methods of applying pesticides.

The actions and interactions of electrostatic, gravitational, thermal, aerodynamic, and inertial effects on pesticide particles are being explored over a wide range of particle-size distributions and turbulence conditions with various kinds of particles, including dusts, sprays, and fogs (10). The attainment of any significant increases in pesticide application efficiency will depend upon an improved engineering knowledge of how to control and apply these forces and effects.

The trend of current research seems to be toward better exploitation of aerodynamic and electrostatic forces to improve pesticide deposition. Aerodynamic forces are much greater and possibly can be applied with less complex equipment. For practical reasons of economy, however, it is generally assumed that the air and fluid must be moving at turbulent flow rates. The resulting aerodynamic environment of the spray or dust contains increased turbulence, or velocity randomness. Because of this turbulence, there is a loss of control which reduces the improvement in deposition efficiency that might otherwise be expected from the increased velocity. Study of the nature of turbulence and its effect on fine particle behavior is currently part of the USDA research program on pest control equipment (3).

Electrostatic forces, while much smaller than aerodynamic forces, do not induce turbulence. Industrial experience with electrostatic spraying has generally been quite favorable (2). A modest amount of work on the use of electrostatic spraying and dusting has been steadily conducted since about 1950 (22). Experimental results have indicated that, under certain conditions, a significantly greater amount of material will be deposited on plants when particles are charged. For example, recent field studies (8) have found that on beans and on corn, only half to two-thirds the amount of electrostatically charged dust will yield pest control equal to conventional application. Several companies are now manufacturing dusters and sprayers which use electrostatic charging as a means of improving deposition. Much of this work has also shown electrostatic charging to be rather inconsistent in its effect, in fact, sufficiently inconsistent to discourage further work (5). It has been found recently that this variability can be reduced in dusts by use of dust which has a high electrical resistance.

The non-uniformity of spray and dust particles also contributes to the lack of control of pesticides. All forces which affect particle behavior are strongly influenced by particle size, and a twenty-fold range of sizes for a given dust or spray is common. In view of this range of sizes, it is not surprising that there are large variations in particle behavior. Most methods for producing uniform drops have been restricted to use in the laboratory. Some devices which have been developed recently for field use produce fairly uniform spray (24, 29). Perhaps this type of equipment can be used in future research to determine the best particle size for coverage of various plants and for best pesticidal effect. Research on the effect of particle sizes should be accelerated by the availability of new semi-automatic equipment for sizing and counting particles. In the past, the magnitude of the problem of counting and sizing has been such as to deter the study of particle size effects. Droplets were observed through a microscope or as projected on a screen and manual counts and size measurements made. Such a procedure was terribly time-consuming. In our own research, the Agricultural Engineering Research Division presently uses a flying-spot particle analyzer which scans photographic negatives of solid particles or liquid droplets which have been recorded on 35 mm. high-contrast film. The instrument, by use of on-line card punching equipment, prepares a tabulation on cards of size distribution, distances between particles, total area covered by the drops, and total area of space between drops. This ability to perform high-speed counting and sizing may seem to be of minor significance to the layman, but it is of the highest importance to the research worker for he cannot know for certain the improvements he has made until he can measure the results.

Other Chemical Application Methods

Spraying and dusting equipment is relatively simple, and is quite reliable and flexible in application. Because of these features, it was easy to overlook study of the efficiency of application by spraying and dusting. There is still not a great deal of data on the question, but the limited measurements made to date indicate that in row-crops these processes are fairly inefficient because they result in applying perhaps 15 percent or less of the chemical on the crop. At the same time that we attempt to improve these processes, we perhaps ought to investigate other methods of applying chemicals to plants and animals.

As frequently as brushes and rollers are used for applying paints, cosmetics, adhesives, and other materials to solid surfaces, it is surprising that so little effort has been made to use them for applying pesticides. Early work with soft synthetic foam rollers encountered difficulties of fouling with dust from plants and of inconsistent metering (14). However, recent experience with roller brush application of systemic insecticide to plant stems seems to have encountered less difficulty (28).

Foam also might be a useful carrier for applying pesticides (1, 4). Properly formulated, it has the property of high surface-to-volume ratio and good wetting and deposition behavior. It can be directed to a target by auxiliary air currents in a continuous flow. In addition, spun filament "cob-web", water-soluble polymer films, and many other approaches may have possibilities. In retrospect, it would appear that more effort should be directed toward chemical application methods which do not use spray or dust.

Summary

(1) Pests live in an environment which has chemical, biological, and physical components. Any and all of these environments can be manipulated for pest control.

(2) Chemical and biological methods, being newer and more familiar to biological scientists, may tend to overshadow the possibilities of physical methods, unless a deliberate effort is made to consider and investigate the physical methods.

(3) Physical control may be possible through changes in the mechanical, thermal, sound, or radiation environment.

(4) Study of the behavior and life cycle of pests should deliberately include observation of physical behavior, to permit a broader choice of physical control methods.

(5) Cooperative research on pest control among biological scientists, chemists, and engineers should consider physical problems involved with biological and chemical control, as well as physical control methods *per se*.

(6) Some combination of control methods is likely to be the system which optimizes control under monoculture conditions over a long period. Such an integrated system will likely contain physical and biological approaches.

References

(1) Barrentine, W. L. and C. G. McWhorter. New spray techniques for directed post-emergence weed control in row crops. Abstracts of 1966 meeting, Weed Society of America, 1966.

2) Brazee, R. D. and W. F. Buchelé. Electrostatic precipitation of pesticidal dusts, an outline of research and literature. U. S. Dept. of Agriculture publication ARS-42-29. July 1959.

(3) Brazee, R. D. Particle size distributions in Brownian motion. U. S. Department of Agriculture publication ARS-42-78. November 1963.

(4) Bouse, L. F. Personal communication. 1965.

(5) Bowen, H. D., W. M. Carleton, and Peter Hebblethwaite. Application of electrostatic charging to the deposition of insecticides and fungicides on plant surfaces. Agricultural Engineering *33*:347-350. June 1952.

(6) Burt, E. C., M. E. Merkl and T. B. Daniels. Boll weevil control in a field experiment with a machine designed to destroy shed cotton squares. U. S. Department of Agriculture publication ARS-42-121. August 1966.

(7) Callahan, P. S. Electromagnetic communication in insects—elements of the terrestrial infrared environment, including generation, transmission and detection by moths. Presented at AAAS meeting, Section O, Agriculture, Montreal, Canada, December 1964.

(8) Casselman, T. W., C. Wehlburg, W. G. Genung, and P. L. Thayer. Field evaluation of the electrostatic charging process for dusts. Paper No. 65-647 presented at American Society of Agricultural Engineers Meeting, December 7-10, 1965.

(9) Carleton, W. M. Integrated pest control systems. Presentation before FIEI Power Sprayers and Dusters Council, Washington, D. C. November 15, 1966.

(10) Carleton, W. M. and R. D. Brazee. Physical and engineering aspects of pest control. Publ. No. 1402, NAS-NRC, pp. 169-184. Proceedings of a Symposium on Scientific Aspects of Pest Control, Feb. 1-3, 1966.

(11) Carlson, Stanley D., John S. Smith Jr., and James M. Stanley. Moth visual potentials in response to middle ultraviolet radiation. Unpublished information, 1966.

(12) Corley, T. E. and W. T. Dumas. Engineering for weed control in the changing south. Presented at the Southern Weed Conference, Dallas, Texas, Jan. 19, 1965.

(13) Earp, U. F., J. M. Stanley and J. J. Lam. Spectral response of hornworm moths. Transactions of ASAE *8*(2): 183-185, 1965.

(14) Gebhardt, M. H. Personal communication. 1961.

(15) Hollingsworth, J. P. Attracting insects with radiant energy. Conference proceedings: Electromagnetic Radiation in Agriculture. Illuminating Engineering Society and the ASAE. pp. 23, 29, and 33. October 1965.

(16) Illinois Agricultural Statistics, Weed Control used by Illinois Farmers, 1965. Illinois Crop Reporting Service, Ilinois Dept. of Agriculture—USDA, Bulletin 65-6, Dec. 1965.

(17) Kay, Burgess L. Paraquat for range seeding without cultivation. California Agriculture, Oct. 1966.

(18) Knake, Ellery. Giant foxtail, a robber in your fields. Illinois Research, Summer 1960, University of Illinois Expt. Station.

(19) Knake, E. L., T. D. Hinesly and R. D. Seif. Can herbicides replace cultivation in Illinois? Crops & Soils, Jan. 1965.

(20) Knake, Ellery L., Fred W. Slife, and Robert D. Seif. Flame cultivation for corn and soybeans. Weeds, Jan. 1965.

(21) Knake, Ellery L. and Fred W. Slife. Competition of *Setaria faberii* with corn and soybeans. Weeds, Jan. 1962.

(22) Kumkel, Wulf B. and J. W. Hansen. A dust electricity analyser. Review of Scientific Instruments, 21:308-314, April 1950.

(23) Liljedahl, L. A. The systems approach to pest control. Presentation at Symposium on Low-volume Application of Chemicals. Sponsored by the Council on Pesticide Application, Chicago, Oct. 19, 1966.

(24) Liljedahl, L. A. Unpublished work. 1966.

(25) Moolani, Moti K., Ellery L. Knake and Fred W. Slife. Competition of smooth pigweed with corn and soybeans. Weeds, April 1964.

(26) Nelson, S. O. Insect control possibilities with electromagnetic and sonic energy (Abstract). Proceedings of the Nebraska Academy of Sciences. p. 75, April 1965.

(27) Nelson, S. O. and J. L. Seubert. Electromagnetic and sonic energy for pest control. Proceedings of Symposium, National Academy of Sciences 1966.

(28) Reeves, B. G., L. H. Wilkes, R. L. Ridgeway, and D. A. Lindquist. Design and evaluation of equipment for basal application of systemic insecticides to cotton plants. American Society of Agricultural Engineers paper 66-106. June 1966.

(29) Roth, L. O. and Jay Porterfield. Liquid atomization for drift control. American Society of Agricultural Engineers paper 65-156. 1965.

(30) Schoenleber, L. Personal communication. 1966.

(31) U.S.D.A. Policy on Pesticides. Secretary's Memorandum 1565, December 23, 1964. U. S. Department of Agriculture, Washington, D. C.

(32) Triplett, G. B. Jr. and D. M. VanDoren. Can herbicides replace cultivation in Ohio? Crops and Soils, Jan. 1965.

(33) Wiese, A. F. and O. C. Burnside. Higher sorghum yields with pre-emergence herbicides. Crops and Soils, Jan. 1965.

(34) Wicks, G. A. Herbicides during the fallow season in wheat rotations. Crops and Soils, Jan. 1965.

Geological Society of Washington: Proceedings For 1966

All meetings were held in the John Wesley Powell Auditorium and President John T. Hack presided except where noted otherwise.

877th Meeting

The 877th meeting of the Society was held on January 12.

Informal Communication. William E. Davies reported on frost-riven rock at Jacks Mountain, Va. Brian Skinner reported on the structure of opal.

Program

James P. Minard: "Cretaceous-Tertiary Boundary in the North Atlantic Coastal Plain."

Norman F. Sohl: "The Importance of Being Well-Preserved—or, New Jersey Cretaceous Molluscs."

Donald Langmuir: "Geochemistry as a Key to the Origin and Potential of an Aquifer System in New Jersey."

878th Meeting

The 878th meeting of the Society was held on January 26.

Informal Communication. Leopold A. Heindl reported on his trip to Iceland, comparing the table mountains there with those in the southwestern United States.

Program

Robert L. Smith: "The Bandelier Tuff: A Study of Ash Flow Eruption Cycles from Zoned Magma Chambers."

James Gilluly: "Geochronology and Orogeny."

879th Meeting

The 879th meeting was held on February 9. The president announced the deaths of Jewell Glass, Gilbert Grosvenor, and John G. Fairchild.

Program

J. A. Calkins and T. W. Offield: "Structure of the Southern Himalayas, Hazara