California Turfgrass Culture

FORMERLY, SOUTHERN CALIFORNIA TURFGRASS CULTURE

VOL. 16 - NO. 4 OCTOBER 1966

Some Problems in Herbicide Application

by

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Successful use of selective weed killers is dependent upon a number of factors besides differential toxicity of the herbicides. Because our knowledge of the action of these factors is limited, they are frequently the cause of poor selectivity leading either to turf injury or to inadequate weed destruction.

One of the critical aspects of chemical weed control, especially of selective control, is placement of the herbicide for optimum contact with the weed but minimum danger to associated desirable vegetation. It is obvious that the amount of herbicide actually contacting the weed may be a very small portion of the amount applied as a given number of pounds or gallons per acre. This actual dosage, as we may call it, is determined by various characteristics of the plant, application equipment, weather, spray solution and the soil if a soil applied herbicide is used.

All of that portion of the total amount of chemical applied that does not eventually reach an organ or tissue of the weed where it can have a toxic effect may be considered wasted. Anything that can be done to reduce loss of chemical is of economic importance and frequently reduces the danger of injury to desirable vegetation.

The first point at which loss occurs is at the moment of application by drifting of the dust or spray. The hazards of drift are well known, especially when spraying with the phenoxy compounds such as 2-4-D. Loss by drift depends on wind velocity, height above ground at which the application is made and size of the spray or dust particle. The relationship of these factors in spray application is shown in Table 1. As droplet size is increased, loss from drift is decreased. Drift can be reduced by using low pressure nozzles designed to give uniform droplets of medium size and applying as close to the ground as possible on a calm day. Droplets 500 microns (l/50 of an inch) in size will cause little drift problem under these conditions..

From the moment a spray droplet leaves the spray nozzle it is subject to evaporation. The life of a drop of water is approximately proportional to the square of its diameter.A 50 micron drop of water at 20° C and relative humidity of 50% will have a life of about 4 seconds while a 100 micron drop will have a life of 16 seconds. A drop which may be large enough to present little drift hazard when it leaves the sprayer may evaporate to a size so small that it can be carried long distances before it reaches the ground. It is, therefore, wise to avoid spraying when the temperature is high and relative humidity is low if drift is to be prevented.

Another aspect of evaporation which will effect herbicide performance is that some substances dissolved in water at low concentrations may evaporate more rapidly than the water. Then the solution in the droplets will become more and more dilute as they travel from the sprayer to the plant. Spraying when temperatures are not extremely high will partially reduce this danger.

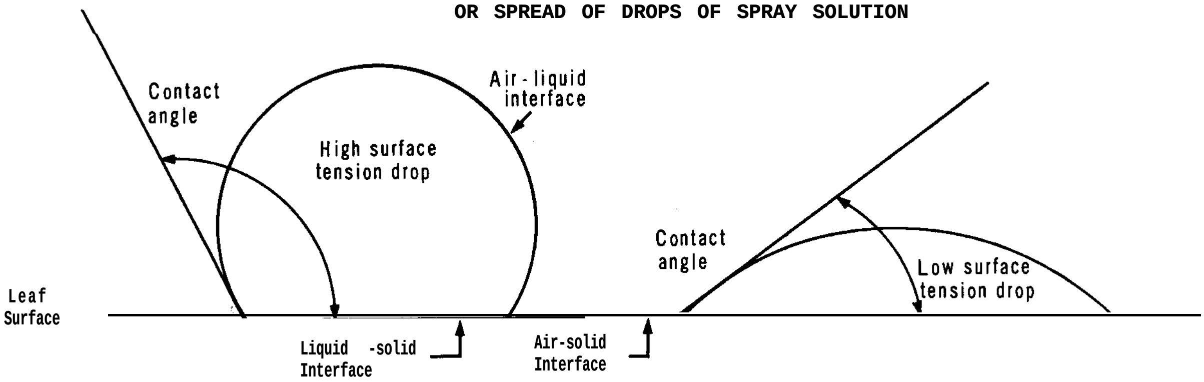
The problem of greatest concern in foliar application of herbicides is retention and spreading of the herbicide over the leaf surfaces. Although fairly large drops are necessary to reduce drift, water drops larger than 250

TABLE 1

DROPLET SIZE (microns)	NATURAL COMPARISON	TIME TO FALL 10ft IN STILL AIR	DRIFT, FALLING 10ft in 3 m.p.h. WIND
5	Fog	66 minutes	3 miles
100	Mist	10 seconds	400 feet
500	Light rain	1.5 seconds	7 feet
1000	Moderate rain	1.0 second	5 feet
3000	Heavy rain	<l.0 second	4 feet

Adapted from V.S.D.A. Farmers Bulletin 2062

Fig. 1 **EFFECT OF SURFACETENSION ON CONTACT ANGLE OR SPREAD OF DROPS OF SPRAY SOLUTION**



microns bounce off the leaves of many plants. In some cases this reflection of drops may be 100%. The extent of this droplet reflection varies from species to species and thus may be related to herbicide selectivity. The amount of spray adhering to the foliage depends upon characteristics of the leaf surface and the spray solution.

In a drop of any liquid the molecules are strongly attracted to each other. Within the drop a molecule is surrounded by other molecules and is equally attracted from all directions. The surface molecules are attracted towards the center of the drop because the number of molecules per unit volume is greater in the liquid than in the air surrounding the drop. Thus, a drop of water tends to contact to as small a surface area as possible because of this inward pull we call surface tension or more correctly surface energy. When a drop of liquid hits a solid surface such as a leaf, it forms a contact angle with the surface as shown in Figure 1. The greater the spread of the drop the lower the contact angle. This contact angle is determined by the relationship of the surface tension of the drop to the energy of the liquid-solid and air-solid interfaces. In general, the lower the sum of the energies of the liquid-air interface (surface tension) and the liquid-solid interface energy to the air-solid interface energy the greater will be the spread of the drop. By adding a surfactant or wetting agent to the spray solution the surface tension of the solution will be lowered and the degree of wetting or spread over the leaf surface increased. The low contact angle gives the drop more stability on the leaf so it is less likely to roll off.

However, the routine addition of wetting agents to all spray solutions is not wise. Structure of the leaf surface also affects the contact angle and the extent of wetting. A thick unbroken layer of wax on leaves of some plants is a primary cause of droplets balling up with a large contact angle. The wax is apparently deposited during the period of leaf growth. Weathering of older leaves causes them to lose much of this wax; thus, the age of leaves may determine their wettability and the need for wetting agents.

Leaves on some plants are covered with stiff, closely spaced hairs that do not touch each other. These hairs are hydrophobic and hold the drop away from contact with the leaf surface. Wetting agents will increase the wetting of these leaves. On the other hand, on some plants the hairs actually assist the wetting process. Mats of soft weak hairs often may be readily wetted and thus allow easy penetration of the spray to the leaf surface below.

It has been shown that the many available wetting agents differ in their ability to improve the wetting of leaves of different species. A superior surfactant for one species may be inferior to others on a different species. Adsorption at the leaf surface (the solid-liquid interface) is affected by physical and chemical characteristics of this surface. Therefore, the different affinities of wetting agents for various leaf surfaces will affect their ability to wet these surfaces.

When water based herbicides are applied at low volume rates the increased spreading attained by using a surfactant will increase their effectiveness. However, at high volume application rates the effectiveness may be decreased because of increased run-off of spray. Even at low volume rates effectiveness of a herbicide may be decreased with the use of a surfactant if applied to weeds that are naturally highly wettable. In this case, run-off may be so great that insufficient toxic chemical remains to kill the weed.

Selectivity of a herbicide may be reduced by addition of a surfactant if a normally nonwettable crop retains more spray as a result. At the same time a normally wettable weed may not be killed by the spray because of the excessive run-off resulting from the lower surface tension.

Loss of herbicide from plant surfaces by action of rain or irrigation sprinklers is a familiar problem. Wetting agents of the anionic or non-ionic types are readily re-dissolved in water so they may aid in the washing of solid particles from the leaves. There may be times, of course, when this assistance in removal of spray residues may be desirable. Cationic wetting agents absorb so strongly on some leaf surfaces that they cannot be removed by water thus increasing the resistance of sprays to washing.

With soil applied herbicides we face the same basic problem of application – to place the chemical where it will be most readily absorbed by the weed with minimum danger to the turf. First, the herbicide must get past the canopy of grass leaves to the soil below. Use of a dry granular material may be the most simple way of accomplishing this. It must be one that does not stick to the leaves but will readily disintegrate when it comes into contact with the moist soil. Coarse sprays of high surface tension will behave in a similar manner.

Once the herbicide reaches the soil it must be carried into and throughout the soil area inhabited by the roots of the plants to be killed. If the plants to be killed are deep rooted, a highly water soluble herbicide should be used, but if the plants are shallow rooted one of lower solubility should be chosen. The amount of rainfall or irrigation water will affect the subsequent downward movement and length of the residual period.

Adsorption of the herbicide onto soil particles also affects the herbicides activity. The amount of adsorption will vary with the herbicide and the soil type. Adsorption removes a portion of the herbicide from immediate activity so the effective dosage will be reduced proportionally to the extent of adsorbtion. This could be sufficient to render a herbicide ineffective.

Adsorption of herbicides is generally reversible so as more water is added to the soil some herbicide is released. The effect then is primarily one of delaying availability. Most plants can tolerate small amounts of toxic substances for long periods of time so if the concentration is kept low at all times by adsorption weed death will not result. Soils high in organic matter as well as clay soils will have a high adsorption capacity. A better understanding of adsorption of herbicides by soil particles is needed, however, it is important at least to recognize it as a major factor determining the intensity and length of herbicidal activity in the soil.

Herbicides may be lost from the soil by chemical breakdown, evaporation from the soil surface, uptake by resistant plants and leaching. Rate of loss by all of these may be retarded by herbicide adsorption onto the soil colloids.

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How To Receive The Greatest Benefits From Turfgrass Irrigation

by Albert W. Marsh, University of California Agricultural Extension Service, Riverside

To receive the greatest benefits from turfgrass irrigation, it is necessary to have good equipment and good management to make the proper decisions for operating this equipment.

NEED GOOD EQUIPMENT

Good equipment should provide (1) ease of application, (2) suitable rate of application, and (3) uniformity of distribution. By ease of application I mean that the equipment should be simple to start and stop at any time of the day or night that might be desired. Ease of application should also mean that the equipment can be operated with a relatively small labor requirement. With the labor market which exists today, we can no longer afford to carry around cumbersome attachments to the various points where sprinklers will need to be located. Solid set systems are more expensive to install initially; but with ever increasing labor costs, they will be cheaper to operate ovet a period of years and will give more satisfactory performance.

A suitable rate of application should be one low enough to avoid any runoff during the length of time sprinklers will be operated. Infiltration studies have shown us that any soil, if it is wettable, has its highest infiltration rate near the beginning of the irrigation. As irrigation continues the rate decreases with time. This decrease in rate is rather rapid at first and then gradually diminishes until there is no longer any appreciable change. If the application rate is high enough to exceed the infiltration capacity of the soil at any time before the irrigation is completed, there will be runoff. Runoff creates a problem, not only from the waste of water but from the accumulation of this excess water elsewhere, often in undesired places. To avoid this problem, the application rate should be low enough that it will not exceed rhe infiltration capacity of the soil throughout the period of irrigation.

If a previously installed system has application rates which are too high, some relief can be obtained by applying the water intermittently. This involves applying the water until runoff just begins, then shutting it off until the water has been absorbed and the soil dried slightly. Then the system can be started again and operated until the irrigation is completed or until runoff starts a second time. If necessary, several cycles of irrigation can be applied each terminating when or before runoff starts. With presently available remote controllers, this can generally be accomplished in one night without the presence of human hands.

In designing irrigation systems, it may be necessary and desirable to plan for different application rates for different areas to be irrigated. If a certain problem area has a low infiltration capacity while the rest of the area to be irrigated has an appreciably higher infiltration capacity, there is no need to design the entire system for the lowest rate. It is sufficient to design the portion of the system covering the problem area at the lower rate and allow the water to be applied more rapidly to the better soil.

The third item of importance under equipment is uniformity of water distribution. No turf manager wants to have part of his turf appearing bad because it does not receive enough water. This can happen if the sprinkler system has poor distribution so that some areas receive only one-third or one-fourth as much water as other areas. Departures of this magnitude have frequently been measured in current turf irrigation sys terns. The turf manager will generally apply sufficient water to produce good looking turf on the areas receiving the lowest application. This means that the portions of the area receiving two, three, four, or five times as much water as the lowest will have an excess of water. The excess water is not only wasteful and costly, but it frequently provokes additional problems such as unnecessary leaching of fertilizers, increased compaction because of overly wet turf, and reduced aeration.

In many systems, the actual uniformity of water received by various areas is even worse than the variance in distribution of the sprinkler system. This occurs when the application rate is too high so that water unable to be absorbed into the soil where it falls, runs to some other part of the area and aggravates the maldistribution of water. Thus, rate of application and uniformity of distribution are a pair which must always be considered together when designing or operating sprinkler irrigation systems.

Tests have been performed to measure both the application rate and uniformity of application of sprinkler systems by placing small containers in a grid work pattern within the sprinkled area. Results from these tests have revealed that ratios between the highest and the lowest application rates are of the order of three, four, or five to one. The best systems measured have a ratio of two to one and very few can match this. It is more common to find three or four to one and five to one is not at all unusual. A few poor systems substantially exceed this.

When irrigating turf it may be more useful to know what percentage of the total area received a fairly good precipitation rather than to know what the extremes were, since the latter may be relatively unimportant. It is suggested that we should examine the fraction or percentage of the area which receives fairly close to the mean application for the entire area. An application departing from the mean by no more than 25 per cent, plus or minus, would seem to be reasonably good and if 75 per cent to 80 per cent of the total area fell within this range, the uniformity of distribution probably would be acceptable. The percentage of the area falling within this range is not necessarily related to the ratio of maximum to minimum application. Further evaluation of this approach is needed.

NEED GOOD MANAGEMENT DECISIONS

In addition to having good equipment, there must be good management decisions made as to when to irrigate, the amount to irrigate, and the time of day to apply water.

The decision about when to irrigate should not be a set irrigation every day, neither should it be a fixed time interval of any other periodic nature because water use rates vary. The decision to initiate irrigation should be based upon observations, both of the turf and of the soil, particularly of the soil. Observation of the turf alone may be too late to accomplish a needed irrigation for good turf maintenance or it may be an observation of a condition brought about by another cause which would result in irrigation when not needed.

If one will use a soil probe or auger, the soil water condition can be felt and observed and will form a good basis for deciding whether to irrigate or not. The decision not to irrigate is often as important as the decision to irrigate and the excessive soil wettness often observed in turf when the soil is examined in this manner should be sufficient reason not to irrigate. Since probing or observing the soil is not always a popular operation, a turf manager can install and use tensiometers. The tensiometer permits him to maintain a continuous record of the soil water condition and provides the most intelligent basis for irrigation timing. Actual use of tensiometers in many well managed turf areas has proved the reliability of basing irrigation timing on tensiometer readings.

Management must also decide how much to irrigate. It is possible to calculate the approximate use of water by turf from climatic information such as evaporation. To the amount so calculated, an addition should be made to allow for the water required to leach salts out of the soil plus that required to compensate for the maldistribution of the sprinkler system. In an ornamental or recreational area there are likely to be portions differing in their water use rates because of the nature of the cover and the exposure. This tends to complicate the problem of making computations for the water use rates and required additions. But measurement of the soil water condition either by observation and feel or by the use of tensiometers provides a means for determining the irrigation required in different areas. When soil moisture evaluation indicates a need for irrigation, an irrigation estimated to be approximately correct is applied. A subsequent soil moisture evaluation following the irrigation reveals whether the application was too little, about right, or possibly too much. At the next irrigation, adjustments in the operating time of the sprinklers can be made in view of this information. Evaluation of the soil water condition following each irrigation indicates whether the adjustments in operating time have produced the desired application of water or whether an additional adjustment is needed. After a few adjustments, the amount of water applied will be very close to the desired quantity.

The best time of day to accomplish an irrigation is another choice of management. The ideal time is when the wind is iow, the water pressure is high, the air temperature is cool, and the area is not being used. The optimum time for all of these conditions is night. The availability of labor and the ability to see has limited nighttime irrigation in the past, but with modern equipment available this is no longer a problem.

The equipment now available which provides a choice of irrigating at any time of day or night includes remote control valves and a timer or controller. The controllers presently available permit preselection of timing and length of irrigation for several valves. They can be set to turn on during the night and shut off when the selected length of application has been made. They can also be set to make repeated cycles of application which helps to overcome the problems of application rates being higher than the soil infiltration capacity.

Tensiometers with electrical connections can be combined with the controller to call for irrigation only when needed but to restrict its actual application to the time of day preselected by the manager. When combined with good equipment for proper application rate and distribution of water, this type of system will give the greatest benefit from turfgrass irrigation.

If desired, the management may incorporate a fertilizer injector with the irrigation system. When properly equipped with an anti-backflow valve, a fertilizer injector permits timely and low cost application of soluble fertilizers to the turf. When added through the irrigation system, there will not be any burn from the application of fertilizers. The distribution of fertilizer added in this manner, however, will be no better than the uniformity of distribution of the irrigation water and should not be attempted if the water application rate from the sprinklers is high enough to produce runoff.

A Low-Application Sprinkler System For Bowling Greens

by Thomas G. Byrne

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A plant's well-being depends upon a satisfactory relationship with all of the many factors which affect its growth. A poor relationship with any single factor can cause a decline in growth, even though all the other growth factors are optimum. This should be axiomatic to the professional horticulturist, but too often we tend to relate crop management problems only to those factors that are clearly discernible and rather easily altered.

Plant-soil-water relations involve many of the basic factors affecting plant growth. The maintenance of proper soil-water relations is an extremely important aspect of landscape maintenance – one that demands a good working knowledge of soil and irrigation management on the part of the horticulturist if he is to meet the increasing demands of his profession.

In California we are dependent upon some type of irrigation system for the maintenance of recreational turf areas that is both functional and aesthetically acceptable. Typically, we rely on sprinkler irrigation for this purpose. The systems in general use apply water at a greater rate than the infiltration rate of water into the soil. In effect, we tend to flood-irrigate with a sprinkler system. The term that we have given to this is sturated-flow irrigation. Ideally, we should be able to irrigate under unsaturated-flow conditions; that is, a turfgrass sprinkler irrigation system should be so designed that its rate of precipitation is at or close to the infiltration rate of the area being irrigated. In addition, the pattern of precipitation should be relatively uniform throughout the irrigated area. Such a system would reduce or eliminate many of the management problems encountered in our recreational turf areas.

There are many reasons why this condition of high rate of application exists in most of our systems. In many instances, we simply are not willing to pay for a better designed system than that which we are presently using. Limitations on placement of permanent sprinkler heads often dictate the use of larger sprinklers with resulting higher rates of application. Very often the reason is simply that we do not know what available equipment is the best for our particular situation. Research for new designs in sprinkler heads someday may give us equipment that will make the design of turf irrigation systems easier, better able to do the job, and perhaps more economical. However, in designing our present-day systems, we must use equipment that is available, and use it to the best advantage.

In earlier studies, we have observed that sprinkler-irrigated turf areas can be used for recreational purposes immediately following an irrigation, with little damage to the soil if the water has been applied to the soil at or below its infiltration rate. We are all well aware that athletic activities on a wet turf can interfere with the game being played upon it. More important, this type of traffic on a saturated soil underlying the turf can seriously damage its structure, which, in turn, generally leads to increased problems in irrigation and maintenance.

Two Approaches to Better Turf Irrigation

There are two basic approaches to the problem of matching the precipitation rate of a sprinkler irrigation system to that of the infiltration rate of a turf area. The first is to modify the soil of the turf area in such a way as to increase the net infiltration rate. The second is to design a low-application-rate system that matches the infiltration rate of the turf situation. Of course, a combination of these two approaches might very well provide a workable solution. The University of California, both at the state and county levels, has been investigating these approaches in cooperation with turf managers and sprinkler irrigation companies. One obstacle to these investigations is that variations occurring in the field sometimes make it almost impossible to separate the effects of the various treatments and techniques that we have studied.

In Alameda County, we have been fortunate to have the use of an old established bowling green on which to test and analyze various techniques to improve the management of a very difficult turf situation. The original bowling green soil was a mixture of Dublin clay loam and coarse sand. Although this soil mixture is quite fertile, it has rather poor physical characteristics when worked or walked upon, particularly when it is saturated. Over the years, thatch buildup from the original Seaside planting, as well as stratification of soil layers from periodic top-dressing, has produced a soil condition which is most difficult to maintain. At present, the predominant grass species is Poa annua, which is not a satisfactory turf grass and which frequently is lost for periods of time due to disease, traffic, and short periods of high temperatures.

Vertical Mulch Not Always Effective

Vertical mulch studies on this particular green have shown the method not effective except for a short period of time. The vertical mulch technique (removal of l-inch diameter soil cores on 2- to 4-inch centers to a depth of 6 to 8 inches and back-filled with a sand-organic mix) has proven successful on some putting greens and bowling greens; however, in these situations the problem was primarily a matter of surface compaction or stratification to a depth of perhaps 3 to 5 inches. On the Berkeley bowling green, it would have been necessary to remove 12- to 14-inch cores by hand to reach the free drainage stratum, and this was not feasible.

Low Application Methods Evaluated

In the course of our vertical mulch studies on this bowling green, we observed very low infiltration rates, which became lower as the irrigation season progressed. Late summer and fall is also the time of the year when play is greatest on these greens. This information led us to a second study – an evaluation of low-application methods of irrigation.

A majority of bowling greens are irrigated with peripheral quick-coupler sprinkler heads or with portable sprinklers attached to hoses. Most of the irrigation systems observed throughout the state apply water at excessively high rates in nonuniform patterns. Adequate coverage of all areas to eliminate dry spots depends primarily on flooding the greens for a sufficient length of time to adequately wet the soil mass of the entire area to the depth of the root zone. As a result, many areas within the green are considerably overwatered – an example of what we have termed saturated-flow. A bowling surface built to game specifications must be level. Unlike a putting green, it doesn't have a natural surface gradient, and excess water builds up on the surface before sheeting off to the gutter.

We designed a portable sprinkler irrigation system, using available irrigation equipment engineered primarily for agricultural crops. We set up several sprinkler studies on the Berkeley bowling green to evaluate the effectiveness of this type of equipment and to determine if it could provide the type of irrigation that would match the infiltration rates of this green. Our studies included the evaluation of three different sprinkler head spacings and a variety of sprinkler heads and orifice sizes. We found that some of the less expensive plastic sprinkler heads gave very poor distribution regardless of spacing. We also found from this study that present-day irrigation equipment engineered for agricultural crop situations, while a vast improvement over many existing systems, still does not provide the degree of uniformity that we consider ideal for this type of turf. Sprinkler heads were spaced 30 feet by 30 feet, using low-angle, single-arm agricultural sprinklers with 1/16-inch nozzle orifices.

Methods Used in Sprinkler Study

To obtain the precipitation patterns we laid out strings on the entire bowling green in a grid pattern at 5-foot intervals. Half-pint plastic ice cream containers were placed at the intersections of all strings. In some areas of the green several cups were placed as closely as 1 foot apart to evaluate precipitation patterns. We were particularly interested in details of the precipitation immediately around the sprinkler heads and at midpoint between the heads. The area of the opened end of the plastic cups was calculated, and from this we compiled a table to convert the volume of water contained after irrigation (measured in cubic centimeters) into inches of precipitation.

Sprinkler runs varied from 3 to 12 hours, but all precipitation data were reduced to inches per hour. Although this green is surrounded by an 8-foot hedge and protected by 30 to 40-foot conifers on the windward side, careful observation of wind conditions were noted during each of the various runs. The velocity of the wind ranged from calm to approximately 4 miles per hour. Large metal washers were placed in the bottom of each lightweight container to prevent accidental spilling or tipping.

The 2-inch portable irrigation system was coupled to one of the existing quick-coupler outlets, and the system was operated at existing water pressures. A pressure gauge was inserted into the quick-coupler, and existing pressures were found to fluctuate between 45 and 52 pounds per square inch (psi). All test runs were made within these pressure limits.

Uniformity a Critical Factor

We encountered no difficulties in getting very low application rates with this particular sprinkler system. However, we found that in working with application rates at or below the infiltration rate of the bowling green, uniformity of water distribution became quite a critical factor. Under conditions of unsaturated-flow irrigation, we cannot depend on runoff from one area to supply water to another. Careful adjustment of the system and a close analysis of its uniformity are more critical than in systems with higher application rates. Data gained from our earlier studies indicated that precipitation rates of .15 inches per hour or greater would 'exceed the infiltration rate of the green. We also calculated from evapotranspiration studies that a maximum of 1 inch of water applied every 5 to 7 days would be necessary for irrigating this bowling green during periods of peak water use.

By using the spacing described above and irrigating for 10 hours during the night, we were able with one particular nozzle to supply adequate water to 95 percent of the green and at no time exceed the infiltration rate. Approximately 45 percent of the green received twice as much water as needed; but this water, because of its low precipitation rate, moved under unsaturated-flow conditions and didn't cause a softness or "squishiness" on the green. We've concluded that minor changes in the position of the portable sprinkler line in two directions during consecutive setups would help even the coverage.

Good Approach to Satisfactory Irrigation

In our opinion, the portable irrigation system described above offers a good approach to satisfactory bowling green irrigation management, utilizing presently available equipment. One properly engineered system can be used to service up to three adjacent greens. Special storage and transport could be constructed relatively easily and at nominal expense. With proper maintenance and competent labor, this system can be a real improvement over existing systems, from the standpoint of both economics and water conservation. More important, such a system can play a big role in improving turf quality and satisfying those who use the turf for recreational purposes.

Liquid Fertilizer Injection

By 0.A. Matkin

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Any system which is imposed or introduced into an horticultural installation should be evaluated for certain features: (1) The first consideration should be for potential improvement of plant response, since this is a basic requirement of all landscape design. (2) Labor and/or maintenance expenditure should be favorably affected by reduction or elimination. (3) The capital investment should be sufficiently low that it can be written off in a relatively short period of time by savings in maintenance costs or growth response obtained from the installation.

Liquid feeding has been practiced for many years, but the principles involved are sometimes confused in the minds of ***users*** and potential users. Following are considerations which should be appreciated:

1. Fertilizer is applied in a pre-diluted form, thus avoiding damage frequently incurred with dry application.

2. Cost of application is virtually eliminated since irrigations must be carried out.

3. The most economic fertilizing materials are available in soluble form, thus making possible maximum fertility at minimum cost.

4. Further economy, safety, and plant response can be attained by "constant" liquid feeding. This procedure involves low concentrations of fertilizer applied at every irrigation. The only labor requirement under an ideal system is that of filling the concentrate tank. Feeding is automatically carried out with required irrigation. Since moisture and fertilizer requirements normally coincide, seasonal requirements for fertilizer are automatically met.

5. Where the majority of the water requirement is met by artificial irrigation, liquid feeding offers the most uniform distribution of fertilizer for plant use. Many experts have erroneously indicated otherwise. It stands to reason that dry fertilizer uniformly applied may be quite non-uniform when irrigated into the root zone due to differences in water infiltration at various locations. With liquid application all water penetrating the soil has the same concentration of fertilizer and therefore provides the plant with the same availability of fertilizer regardless of whether a large or small quantity of water actually reaches or passes through the root zone.

Numerous methods of applying fertlizer in liquid form have been devised. Some of the more common systems are:

1. Metering of dry material into an open ditch water stream.

2. Metering of liquid fertilizer into an open ditch water stream.

3. Measuring of dry or liquid fertilizer into a reservoir for subsequent pumping and application.

4. Utilization of an enclosed tank with a venturi system for distributing the dry or liquid materials into water lines under pressure.

5. Use of injection pumps or chemical feeders commonly electrically operated to supply liquid concentrate into the water line under pressure.

6. Injection of liquid fertilizer concentrate into pressurized lines utilizing energy developed by water meter or water motor system, thus insuring constant proportion.

An ideal system of liquid fertilizer application will provide a number of conveniences and controls.

1. Fertilizer will be injected into the line under pressure in a fixed or easily adjustable dilution ratio of practical range for the purpose intended.

2. The liquid concentrate will be automatically removed from a non-pressurized tank and injected into the pressurized line.

3. Fertilizer will be injected such that the concentration is uniform and equal in all water applied to soil surfaces.

4. The injecting device will perform accurately over the range of flow rates required.

5. Cost and maintenance of the injecting device will be relatively low. Parts should be corrosion-resistant, accurate and reliable, and few, if any, adjustments should be required.

6. Operation will automatically cease and start with water flow.

7. There will be a minimum or negligible pressure drop due to use of the injecting device. If otherwise, the irrigation engineer should be informed before preparing sprinkler design.

There is a wide range of materials that can be used for liquid feeding. The only prerequisite is that they have a fertilizer value and are reasonably soluble. Commonly used materials consist of the following:

Dry ammonium nitrate	– 33.5% nitrogen
Dry di-ammonium phosphate	– 21% nitrogen, 53% P_2O_5
Dry mono-ammonium phosphate	– 12% nitrogen, 62% P_2O_5
Dry muriate of potash	– 60% K_2O
Dry potassium nitrate	– 13% nitrogen, 44% K_2O
Liquid 20-0-O	– Ammonium nitrate liquid
Liquid 32-O-O	– Mixed urea and ammonium nitrate liquid
Liquid 8-24-O	– Ammonia neutralized phosphoric acid
Liquid 0-54-O	– 75% agricultural grade phosphoric acid

(Anhydrous and aqua ammonia solutions are not employed where sprinklers are utilized due to loss by volatilization.)

The above materials are all simples. Prepared liquid such as those listed last do not include potassium, though this element can be supplied as a O-O-12 muriate of potash liquid.

Available equipment for fertilizer injection includes a large number of devices. The number is steadily increasing from a relative few some ten years ago. The experience of the author is necessarily somewhat limited and listing of equipment is therefore limited to those which either indicate promise or have in the author's experience proved satisfactory. A number of devices not listed have been tested andproved unsatisfactory. The list and commentary to follow are an attempt at providing specific sources for special uses:

1. For low flow rate requirements such as the back yard greenhouse hobbist, the following unit is suggested:

Commander Proportioner – Maddox-Moore
1504 E. Riverside Dr., Indianapolis, Indiana

This is a unit having a dilution ratio of approximately 1:125 and capable of handling water flow rate in range of O-7 gallons per minute. It has not been thoroughly tested by this laboratory, but the principle of operation appears to be satisfactory.

2. For low and intermediate flow rates, the following unit is suggested:

Ratio Feeder – H. E. Anderson Company
P. 0. Box 1183, Muskogee, Oklahoma

This unit is available in three sizes, with flow rates between 5 gallons and 50 gallons per minute. The injection ratio is 1:3000 or greater. Unit is basically a water meter using meter power to inject fertilizer. It requires a contact tank to insure adequate mixing since injection frequency is rather wide-spread.

3. Intermediate to moderately high flow rate ranges are available in equipment as follows:

Smith Measuremix – Smith Precision Products Co.
1135 Mission Street, So. Pasadena, California

At least five different units are available from this company ranging from a small unit having a flow rate range of 2 to 15 gallons per minute up to a 6 inch size having a flow rate range of 200 to 700 gallons per minute. Injection ratios are available over a wide range.

4. Specially engineered units can be supplied by various agencies who are experienced in the injection of chemicals into flow streams. It is not possible to list any single agency as a source of supply other than to indicate that engineers familiar with chlorine injection in municipal water supplies may well be able to provide equipment and added components to meet the fertilizer injection requirements. A system currently being tried is that of measuring flow rate by means of the Dall flow tube made by FIF Industries. Information obtained by this unit is conveyed to injection equipment which picks up liquid fertilizer from a storage tank and injects this liquid into the water stream in proportion to water flow. Water flow rate ranges can be handled over any ten-fold range. One company currently working on systems of this nature is the following:

Chas. P. Crowley Co., 5430 Jillson St., Los Angeles 22, Calif.

Where flow rate variation occurs over a wider range than can be handled by any single injector, it is sometimes necessary to include two injectors in parallel such that one will operate when requirements are low and the second will come into operation when requirements are high. Available valve systems will automatically control this. There are also valve systems which can be coupled to clock timers such that fertilizer will be provided during certain periods of the irrigation program and omitted on others. This type system may have use in golf course installation where it is desired to fertilize greens at every irrigation but fairways only intermittently.

CALIFORNIA TURFGRASS CULTURE
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Riverside, California 92502
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CALIFORNIA TURFGRASS CULTURE is sponsored by the Federated Turfgrass Council of California ond is financed by the regional councils and other turfgrass organizations of the state. The Federated Council consists of officers and directors of the regional councils. Subscription to this publication is through membership in one of the councils listed below.