REDUCED XANTHOMONAS AND INCREASED SEED GERMINATION FROM CARROT SEED CROPS IRRIGATED BY DRIP VS SPRINKLER, 2004 AND 2005

Fred Crowe, Marvin Butler, Rhonda Simmons, Claudia Campbell, Caroline Weber, John Weber, Mike Weber, Brad Holliday, and Jim Klauzer

Abstract

In both 2004 and 2005, in paired field comparisons, the amount of *Xanthomonas campestris* pv *carotae* assayed from seed harvested from drip-irrigated carrot seed fields was substantially lower than the amount assayed from seed harvested from sprinkler-irrigated fields. In 2004, this difference averaged only 0.5 log unit, with seed from both dripped and sprinkled fields infested above 10^5 CFU (colony forming units) Xanthomonas/10,000 seed. In 2005, this difference ranged from 1 to 2 log units. In 2005, most seed lots from drip-irrigated fields were well below 10^5 CFU/10,000 seed, and all seed lots from sprinkler-irrigated fields were above 10^5 CFU/10,000 seed. Based on 10^5 CFU/10,000 seed as the criterion for seed treatment, in 2004 seed from all fields required hot water treatment to reduce Xanthomonas. In 2005, seed from most drip-irrigated fields did not require hot water treatment, but seed from all sprinkler-irrigated fields required hot water treatment. More importantly, based on irrigation studies from 2004, 2005 and earlier, seed germination consistently was 3-5 percent higher for seed from drip-irrigated vs. sprinkler-irrigated fields. Higher percentage of germination allows for greater tolerances when hot water treatment is required. Therefore, drip irrigation of carrot seed crops was beneficial by both reducing the risk that a seed lot would require treatment, and by elevating the tolerance of seed lots to reduced germination from the hot water process itself. Differences in weather between 2004 and 2005, most likely the much lower late summer precipitation, may have accounted for less Xanthomonas on seed harvested from drip-irrigated fields in 2005 than in 2004. Limited data from several furrow-irrigated fields suggested that populations of Xanthomonas on plants and seed were intermediate between those associated with dripped or sprinkled fields. Additional information is presented on a field trial in progress in which various bacterial control products were fall-applied in 2005 for control of Xanthomonas during 2006.

Introduction

Bacterial blight of carrots is incited by *Xanthomonas campestris* pv *carotae* (hereafter simply referred to as "Xanthomonas")**.** In carrot seed fields in central Oregon and central Washington, bacterial blight generally is mild and occasional, although high disease incidence does flare up in some fields in some years. More problematic is that Xanthomonas is abundant on seed harvested from these regions, even in the absence of bacterial blight disease. By planting out variably infested lots of seed, and measuring the incidence of bacterial blight that resulted in commercial carrot plantings in two different years, a purported economic threshold was established for seed lots planted in central California in the late 1990's (Umesh et al. 1998). It is unlikely that any one such study truly represents a realistic economic threshold risk for all commercial fields in all regions in all years and under all management systems, although it may reasonably represent the risk in central California. Nevertheless, this seed infestation level (10^5 CFU Xanthomonas/10,000 seed = 10,000 CFU per 10,000 seed or 1 Xanthomonas per seed) has been accepted as a standard by many in the carrot industry. These assay numbers are typically based on using the highly selective growth medium for carrot Xanthomonas (XCS medium [Williford and Schaad 1984]), and the treatable threshold might be different for other selective media. Seed lots found infested above this level typically are hot water treated to reduce the infestation level treatment (Strandberg and White 1989). Seed lots infested below this level typically are accepted for planting without hot water treatment. Hot water treatment seems to either eradicate Xanthomonas from seed, or reduces it below detection levels.

In addition to actual disease, costs to the seed production system result from (a) hot water treatment, (b) reduced seed germination from the effects of hot water treatment, (c) rejection of seed lots if the resultant germination drops too low, and (d) any chemical applications made to seed fields in the attempt to reduce Xanthomonas. Research described here was undertaken towards reducing Xanthomonas levels on carrot seed and reducing the need for hot water treatment.

Seed assays evaluate the Xanthomonas that can be washed from seed (Williford and Schaad 1984, Kuan et al. 1985, Umesh et al. 1998). While Xanthomonas may be present on seed prior to harvest, Xanthomonas is abundant on carrot foliage and stems, and additional Xanthomonas may become attached to seed during harvest operations, associated with dust and debris in the combining process. Carrot seeds have spines that might help collect such dust and debris, but these spines are removed (deburred) during the seed cleaning process. Determination of seed quality, including both germination and infestation levels, are determined after deburring. We suspect that deburring and other manipulations of seed during the cleaning and sizing process remove a substantial amount of harvest dust and small debris that may carry Xanthomonas, along with Xanthomonas directly attached to the spines. This was not investigated in this study; all seed was evaluated after normal seed deburring, cleaning, and sizing processes were complete.

Care is taken to plant Xanthomonas-free seed and stecklings in carrot seed fields. Measured by assays of washed foliage, stems, and umbels using XCS medium, incidence of Xanthomonas in seed fields initially is low. Sources of initial inoculum in seed-to-seed fields may be from nearby harvesting operations of overlapping carrot seed crops in central Oregon. Where seed fields are more widely spaced and where crop-to-crop green bridges don't occur (central Washington), Xanthomonas infestations still occur, but commonly arise later in the season. Denser foliage and higher temperatures may allow Xanthomonas to increase faster in central Washington toward the end of the season (this is speculation by F. Crowe). By harvest time, plant surface populations are high in both Oregon and Washington even in the absence of bacterial blight, and seed lot infestations are well associated with high recovery of Xanthomonas from plants late in the season. Seed contamination levels of 10^6-10^8 CFU/10,000 seed are common (Du Toit et al. 2005).

Foliage and seed estimates of Xanthomonas populations above were determined by washing procedures that dislodge bacteria from plant surfaces. Because foliage was chopped prior to washing, internally located bacteria also may contribute to the assayed populations. However, prior to any outward disease symptoms, plant pathogenic bacteria may become tightly associated with plant cells and surfaces, either endophytically within cells or embedded in cell walls, and such bacteria are particularly difficult to treat with surface-acting antibacterial products (Wilson et al. 1999). In addition, plant pathogenic bacteria commonly form thin resistant biofilms on surfaces. Estimates of the proportion of the total leaf population not easily washed from foliage for a bean Xanthomonas ranged up to 70 percent for some samples, and commonly were 30-50 percent (Jaques et al. 2005). Further, in an earlier report to the California Fresh Carrot Advisory Board, we reported very high internal populations of carrot Xanthomonas in approximately 5 percent of carrot seed plants, which suggested that Xanthomonas had reproduced to high levels within those plants. As a result, carrot seed and plant assays should be understood not as representing all the potential Xanthomonas present, but as relative measures of easily recoverable Xanthomonas. Even plants and seed that assay as zero Xanthomonas could harbor difficult to extract or culture Xanthomonas cells.

Currently, the majorities of carrot seed fields in central Oregon are irrigated by either sprinkler or furrow irrigation, although the proportion of fields irrigated by drip has increased annually since 2000. Because bacterial populations typically increase and spread in association with free moisture on foliage, especially splashing (but also equipment movement, etc.), the mode of irrigation has always been a question with respect to Xanthomonas in carrot fields. Nevertheless, anecdotal observations by growers and seedsmen and the survey by Du Toit and Crowe during 2003 and 2004 (Du Toit et al. 2005) failed to note any strong differences in seed lot infestation with respect to mode of irrigation. Evidence gathered in 2003 suggested that drip-irrigated test plots located alongside sprinkler-irrigated fields initially were lower in Xanthomonas infestation, but that bacteria from the sprinkled areas moved into the dripped areas. In the 2004 and 2005 studies discussed here, we utilized widely separated comparisons to avoid this complication. It should be noted that all seed-to-seed fields in central Oregon are sprinkled for seedling emergence in the fall, and those that will be furrow- or drip-

irrigated in the following season are converted to furrow or drip irrigation beginning in spring.

In 2000 and 2001, research was conducted at the Central Oregon Agricultural Research Center (COARC) to evaluate agronomic aspects of drip irrigation on seed carrots. Benefits were shown to include a significant reduction in water usage, increased seed yields, and a possible decrease in disease. As a result of this research, drip irrigation was placed in three commercial fields in 2002. While disease results were inconclusive, yields increased by an average of 60 percent and water usage was generally half of that used under sprinkler irrigation. Given these promising results under commercial conditions, the experiment expanded to four carrot fields in 2003. It was shown that drip irrigation allowed growers to plant seed carrot fields on otherwise unsuitable terrain. Water usage results again showed that water could be reduced by 50 percent or more under drip irrigation. When compared to furrow irrigation, water usage was reduced by almost 75 percent. In all cases, drip irrigation resulted in elevated percentage seed germination.

Our goal in 2004 and 2005 was to more closely compare bacterial blight incidence in central Oregon seed carrot fields irrigated by drip, furrow, or sprinkler, and better integrate disease and agronomic evaluations.

Materials and Methods

Xanthomonas populations were monitored through to harvest in five drip-irrigated fields in 2004 and four drip-irrigated fields in 2005, respectively. Nearby sprinkler-irrigated fields were used as comparisons because of concern about movement of Xanthomonas when the sprinkler and drip were side by side. A limited number of furrow-irrigated fields were included in some comparisons. Each set of comparisons included the same carrot variety, seed source, soil types, and microclimates. Although farmed by different growers, each crop was managed similarly, especially for a given variety.

The carrot fields included in Xanthomonas analysis were seed-to-seed and were planted according to the seed contractor's specifications in mid-August 2003 and 2004, respectively. All fields were sprinkle irrigated in the fall. Those to be irrigated by other means in the following year were converted to drip or furrow irrigation in the spring. Drip-irrigation systems designed specifically for each field were assembled and installed by grower cooperators, under the direction of Jim Klauzer of Clearwater Supply during May and June. Fertilizer and pesticide treatments were applied the same on both the drip-irrigated and sprinkler-irrigated plots.

The drip-tape delivered water at the rate of 0.22-gal/min/100 ft. The tape was installed 2 to 4 inches below the soil surface and offset 3 to 5 inches from the carrot row to minimize disturbing the roots. After installation, the T-Tape was flushed and the ends rolled over and secured. The first irrigation with the drip tape lasted for 24 to 48 hours in order to set the wetting pattern. Watermark soil moisture sensors were placed in groups of three at multiple locations in each of the drip-irrigated plots to track soil moisture and determine

irrigation scheduling. The sensors were installed 8 inches deep in the carrot row. The target soil moisture level was -40kPa throughout the season.

Moisture readings were taken two times per week from mid-May to mid-August. Additionally, growers had an AM400 (generally referred to as a Hansen). The Hansen allowed them to access their soil moisture readings at any time. Whenever the average of the readings reached the target level, growers were requested to irrigate the drip carrots. The length of the irrigation set varied from 4 to 12 hours. The sprinkler-irrigated plots were managed by growers according to their standard practices. Three Watermark soil moisture sensors were placed in the sprinkler- and furrow-irrigated plots, including the comparison fields, to track the soil moisture.

Plots were harvested by grower cooperators using commercial equipment in September of each year. Following harvest, cleaned seed samples were collected from the seed taken from each field, using commercial seed industry sampling protocol. Such seed sampling combines small aliquots of seed from many parts of a lot of seed so is considered a representative sample. Seed cleaning was conducted by Central Oregon Seed (COSI) according to the specifications in the contract. Seed testing was conducted commercially following Association of Seed Analysts standards.

None of the planted seed was available for testing for Xanthomonas. In previous studies no Xanthomonas was found on any seedlots used in central Oregon (Du Toit et al. 2005). We assume that seed companies direct Xanthomonas-free seed into central Oregon carrot plantings to increase the chance that Xanthomonas will not develop in the seed field.

Xanthomonas populations were monitored in matched sets of fields beginning in the spring of 2004 and 2005. Typically, irrigation in central Oregon begins in late April or soon after. Because irrigation systems were installed in the spring, mid-April was used as an initial preirrigation baseline sample. At several times from spring to near harvest, samples were collected from each set within a day or two.

Sampling and plant assays were conducted as per our previous survey (Du Toit et al. 2005). At each sampling date, either whole small plants or representative parts of large plants (foliage, stems, and flowers) were collected separately for 30 plants. Hands and equipment were sterilized between each sample, and each sample was collected into a new plastic bag. Samples were kept cool until processed in the lab. If necessary, samples including umbels and stems were chopped. Samples were washed for 1 hour in phosphate buffer (12.5mM PO_4, pH 7.1), prior to coarse filtering and dilution plating onto XCS agar, a semi-selective medium for *X. campestris* pv. *carotae* (Williford and Schaad 1984). Petri plates were observed within 1 week and the number of CFU of Xanthomonas was determined per gram of dry weight in the sample.

Per sample, 10,000 seed were soaked overnight at 4^{o}C in 100 ml of saline (0.85 percent NaCl). Two drops of Tween 20 were then added to each flask, which was placed on a rotary shaker for 5 minutes, diluted and then plated on XCS agar. Seedlots were assayed three times each. Incidence of plant infestation was simply the proportion of plants on

which Xanthomonas was found, typically expressed as a percentage. Additionally, for plants that tested positive for this pathogen, the mean of the log(CFU) was recorded (e.g., there might be 10 of 30 plants with Xanthomonas, and the mean of the log(CFU) for the 10 positive plants might be 10^6, even though no Xanthomonas was found on the other 20 plants).

Results

Seasonal information: Seasonal temperature and precipitation data are shown in Figures 1 and 2, respectively.

In 2004, extended spring rains delayed installation of drip systems and eliminated the need for irrigation during the spring of the season. This situation was more pronounced in 2005, where the spring was even wetter than in 2004. Both years were considered abnormal in this respect for this high desert region. We would not expect irrigation-based Xanthomonas differences to develop until after irrigation actually began. Thus, a true base-line comparison for initial Xanthomonas populations in fields occurred whenever irrigation actually began. (This is discussed later and is represented in Figures 4 and 7.)

In 2004, seed maturity and harvest followed a period of additional wet weather in August. In 2005, no wet weather occurred between late July and late September, so all seed maturity and harvest was completed during dry weather in 2005.

Agronomic and irrigation data: For purposes of this report, we focus primarily on the disease aspects of this study and only briefly abbreviate the agronomic and water use results, assuming that seed quality is of most interest to our audience.

In both 2004 and 2005, as in previous years of drip- vs. sprinkler-irrigation comparisons, seed yields were increased in most but not all drip- vs. sprinkler-irrigated fields. Water savings from drip irrigation were very substantial in all field comparisons, ranging up to 50 percent.

The proportion of seed that germinates is a primary aspect of seed quality. Except for 1 year (2003), seed from drip-irrigated fields had increased percentage germination compared to seed from sprinkler-irrigated fields. Data for 2004, 2005, and some previous years are shown in Table 1. Seed was not available for every field in each comparison, so fewer fields are represented in 2004 and 2005 than are represented below in the irrigation comparison study. In general, the percentage increase in germination was 3-5 percent greater for drip- vs. sprinkler-irrigated fields. Considering the reality that hot water treatment may reduce percentage germination by a comparable amount, these results demonstrate a major advantage of drip irrigation over sprinkler irrigation for seed lots in which Xanthomonas is at treatable levels.

Additional benefits associated with drip irrigation compared to sprinkler irrigation included a reduction in weeding time, because less area watered reduces the area of

active weed growth. Additionally, labor associated with irrigation is needed more intensively during May or June rather than in July and August when labor is at a premium. Lodging occurred less frequently when drip irrigation was used. Drip irrigation has made it possible for growers to plant carrots in fields where the terrain had made it prohibitive in the past. This allows growers to have more land available for rotation to grow high-valued seed crops. Another potential benefit of drip irrigation is reduced fertilizer application when compared to broadcast application. Given the average increase in seed yields over the past 3 years, it is estimated that drip may pay for itself within 2 years. A fuller report on seed yields, water usage, and the economics of drip vs. sprinkler irrigation of carrot seed can be obtained by contacting Marvin Butler at the Central Oregon Agricultural Research Center (marvin.butler@oregonstate.edu).

Xanthomonas data*: *2004: Although Xanthomonas sampling was initiated in April, irrigation was delayed by spring rains, and splashing of bacteria could occur in all fields. Thus, June 1 was considered the baseline sample date for divergence in Xanthomonas populations between drip- vs. sprinkler-irrigated fields. The mean proportion of plants from which Xanthomonas was recovered is shown in Figure 3 for individual field comparisons, and these data are summarized in Figure 4. Figure 4 shows mean separations for significance level of 5 percent based on analysis of variance, along with information on irrigation and rain events.

Prior to any irrigation, the proportion of plants already harboring Xanthomonas populations in fields to be sprinkled averaged 21 percent in late April, and that in drip fields averaged about 15 percent, with a combined average of 19 percent. Xanthomonas plant recovery incidence increased in drip fields to 25 percent around July 10, whereas the incidence in sprinkler-irrigated fields increased from about 20 to 60 percent. On average, sprinkler-irrigated fields were irrigated five to six times during the June 1 to July 10 period. The three-fold difference in July incidence between drip- vs. sprinkler-irrigated fields suggests that irrigation type had a tremendous influence on plant infestation incidence, even with fewer irrigations contributing than in a normal season.

Very heavy rainfall was recorded in central Oregon late in August 2004, as carrot seed plants were approaching maturity and before the September 1 sampling period. The proportion of plants with Xanthomonas in sprinkler-irrigated fields increased from 60 to 76 percent between July and September, and in drip-irrigated fields the increase was from 25 to 67 percent. We had hoped that incidence would remain low among drip-irrigated fields during this same period, but it seems likely that the heavy August rain promoted rapid spread. Statistically, however, the difference between 76 and 67 percent was still significant ($P < 0.05$).

Population data from plants that assayed positive for Xanthomonas are not shown for any date, but populations of 10^4-10^8 CFU/g of dry tissue were common whenever Xanthomonas was present on a plant. These figures are consistent with data gathered in earlier surveys (Du Toit et al. 2005). As we found in our earlier surveys, once plants become infested, populations tend to become somewhat high even though symptoms do

not generally develop. Thus, the main effect of irrigation type was simply the reduction in proportion of plants with Xanthomonas.

Xanthomonas seed assay data for the five field sets for 2004 are shown in Figure 5, expressed as the mean log(CFU) averages. Seed from sprinkler-irrigated fields averaged log(CFU) just over 7, whereas seed from drip-irrigated fields averaged about 6.5 mean log(CFU). This difference was statistically significant ($P < 0.05$). A log(CFU) rating of 6.5 is higher than our hoped-for log(CFU) target of 5 (i.e., 10^5 CFU/10,000 seed).

2005: For 2005, spring rains were even more abundant than in 2004. Initial irrigation was delayed until around mid-June. The proportion of plants infested with Xanthomonas for each of four field comparisons is shown in Figure 6, and an average and summary of these fields is given in Figure 7. Figure 7 also shows information on irrigation and rainfall events for 2005. The proportion of plants infested was highly variable and not as consistent with respect to irrigation type as was found in 2004. Presumably, excessive rains splashed bacteria widely among and within fields throughout the region even before irrigation began. As the season progressed, the proportion of plants with Xanthomonas was even higher in drip- than sprinkler-irrigated fields, although not statistically different. The number of bacteria per plant, expressed as the average log(CFU), was 10^6-10^9 (data not shown), above that found in 2004. These figures, too, were within the range found in earlier surveys (Du Toit et al. 2005).

Based on abundant and widespread infestation of Xanthomonas in both drip- and sprinkler-irrigated fields, we expected few differences in seed assays for the various field comparisons in 2005. Nevertheless, there was substantially less Xanthomonas recovered from seed in drip- vs. sprinkler-irrigated fields (Fig. 8); these were much greater differences than were found in 2004. In fact, seed from drip-irrigated fields in several field comparisons (sets 1 and 4) were 2 log units lower in Xanthomonas than seed from their sprinkler-field comparisons (sets 1 and 4), which is a 100-fold less Xanthomonas. The difference was at least 1 log unit lower (10-fold less) for the other two fields. More importantly, for three of the four field sets, the seed from drip-irrigated fields assayed below 10^5 CFU/10,000 seed, below the threshold for hot water treatment. Seed from all four sprinkled fields was well above 10^5 CFU/10,000 seed and would require hot water treatment.

Discussion

It is assumed in our results and discussion that there was no difference in recovery efficiency of Xanthomonas from plants and seed based on the type of irrigation used, from year to year, or other factors.

Drip irrigation, compared to sprinkler irrigation, resulted in lower recovery of Xanthomonas from carrot seed, as long as there was sufficient isolation from sprinkler irrigation. This was found for both 2004 and 2005, years in which field separations were substantial, but less so in earlier years when drip-irrigated plots were in close association

with sprinkler-irrigated fields. Whether the final seed infestation was low enough to avoid seed treatment varied with year and field.

Based on the weather patterns seen in 2004 and 2005 and all surveys of seasonal Xanthomonas development, it seems unavoidable that large plant populations may develop in many years, especially if seasonal rains occur. However, very low seed infestation occurred in 2005 in spite of heavy spring rains, whereas high seed infestation occurred in drip-irrigated fields in 2004 when a heavy late-season rain occurred. This suggests that late-season precipitation has much more influence on seed infestation in drip-irrigated fields than precipitation in the early to middle parts of the summer. Sprinkler irrigation promotes plant and seed infestations irrespective of rain events.

Irrigation is manageable, whereas rain events are not. It appears that drip irrigation can capture the advantage of a dry end-of-summer whereas sprinkler irrigation cannot. In some years, therefore, drip irrigation alone may directly result in many seed lots that require no hot water treatment to reduce Xanthomonas. Both springs included in this report were wetter than long-term averages for central Oregon. As a result, the irrigation season was delayed in each year, with less number of irrigations per field (either sprinkler or drip) than in "normal" years. The relative shortness of the irrigation season for 2004 and 2005 may have influenced Xanthomonas development, and population differences associated with irrigation types may have been narrowed. We might expect that in "normal" (drier) years, with longer and drier irrigation seasons, Xanthomonas developing on plants and seed would be substantially less from drip- vs. sprinkler-irrigated fields than was found for 2004 and 2005. However, late summer rains might overcome this advantage in any season, assuming Xanthomonas populations are present.

While not shown here, Xanthomonas data were gathered from several furrow-irrigated fields included in this study, but not in every drip-sprinkle comparison set. In general, the plant and seed Xanthomonas data for drip-irrigated fields were intermediate in comparison to drip and sprinkler irrigation, trending closer to sprinkler irrigation than drip irrigation. No agronomic performance or water usage data were collected from these fields. Past surveys and observations suggest similar Xanthomonas levels in sprinkler- and drip-irrigated fields (Du Toit. et al. 2005). Furrow-irrigated fields become wetter than drip-irrigated fields, and the canopy is more humid (personal observation), which may promote higher Xanthomonas activity than in less-humid drip-irrigated fields.

Drip irrigation studies conducted in central Oregon between 2002 and 2005 demonstrated that seed germination percentages were typically 3-5 percent higher with drip vs. sprinkler irrigation. The reasons for this are not clear, but could be a result of better irrigation and seed development in parts of fields where moisture stress occurs under sprinkler irrigation. Whatever the reason, because hot water treatment tends to lower seed germination a few percentage points, seed from drip-irrigated fields may tolerate such effect and remain above germination tolerances. This perhaps is the most important finding of these studies with respect to general seed quality, although the need for hot water treatment for seed from drip-irrigated fields may be reduced during dry years, also.

All other agronomic and water usage data support conversion to drip irrigation from sprinkler irrigation, and economic analyses (not shown) suggest that the cost of conversion may be reclaimed within 2-3 years. As a result, in central Oregon we can expect more drip-irrigated carrot seed fields in future years, and improved seed quality.

Literature Cited

Du Toit, L.J., F.J. Crowe, M.L. Derie, R.B. Simmons, and G.Q. Pelter. 2005. Bacterial blight in carrot seed crops in the Pacific Northwest. Plant Disease 89:896-907.

Jaques, M.A., K. Josi, , A. Darrasse, and R. Samson.. 2005. *Xanthomonas axonopodis* pv. *phaseoli* var. *fuscans* is aggregated in stable biofilm population sizes in the phyllosphere of field-grown beans. Appl. and Environ. Microbiol. 71:2008-2015.

Kuan, T.-L., G.V. Minsavage, and R.L. Gabrielson. 1985. Detection of *Xanthomonas campestris* pv *carotae* in carrot seed. Plant Dis. 69:758-760.

Strandberg, J.O., and J.M. White,. 1989. Response of carrots to heat treatment. J. Amer. Soc. Hort. Sci. 114:766-769.

Umesh, K.C., R.M. Davis, and R.L. Gilbertson. 1998. Seed contamination thresholds for development of carrot bacterial blight caused by *Xanthomonas campestris* pv *carotae*. Plant Dis. 82:1271-1275.

Williford, R.E., and N.W. Schaad. 1984. Agar medium for selective isolation of *Xanthomonas campestris* pv *carotae* from carrot seeds. Phytopathology 74:1142 (Abstract).

Wilson, M., S.S. Hirano, and S.E. Lindow. 1999. Location and survival of leaf-associated bacteria in relation to pathogenicity and potential for growth within the leaf. Appl. and Environ. Microbiol. 65:1435-1443.

Table 1. Percentage germination of carrot seed from paired drip- vs. sprinkler-irrigated fields in central Oregon, 2000-2005.

Year	Number of field comparisons	% Germination drip	% Germination sprinkle
2000	1	93	88
2001	1	86	77
2002	3	91	88
2003	3	91	91
2004	4	94	91
2005	3	93	87

Figure 1. Daily precipitation recorded at Central Oregon Agricultural Research Center, Madras, Oregon for 2004 and 2005.

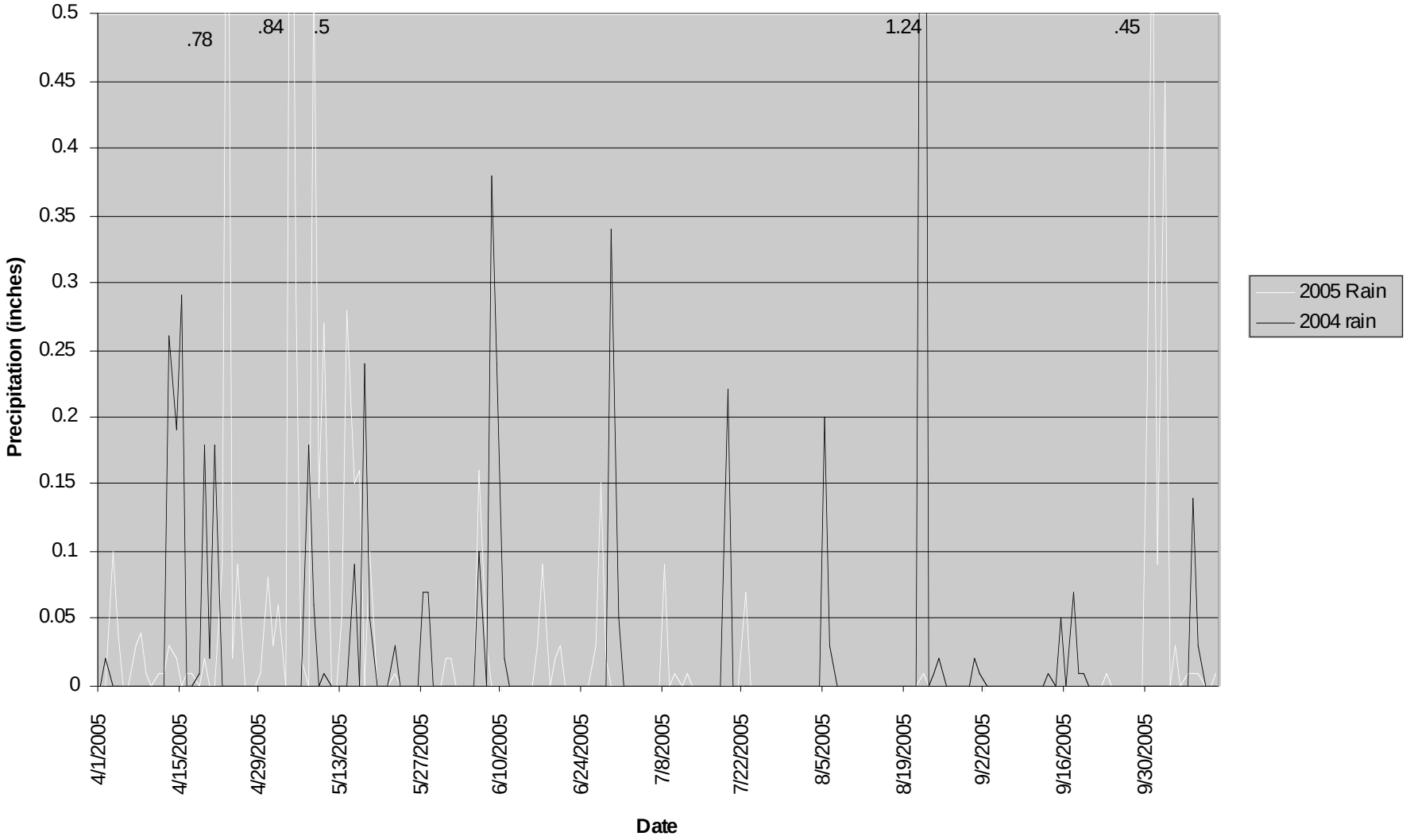
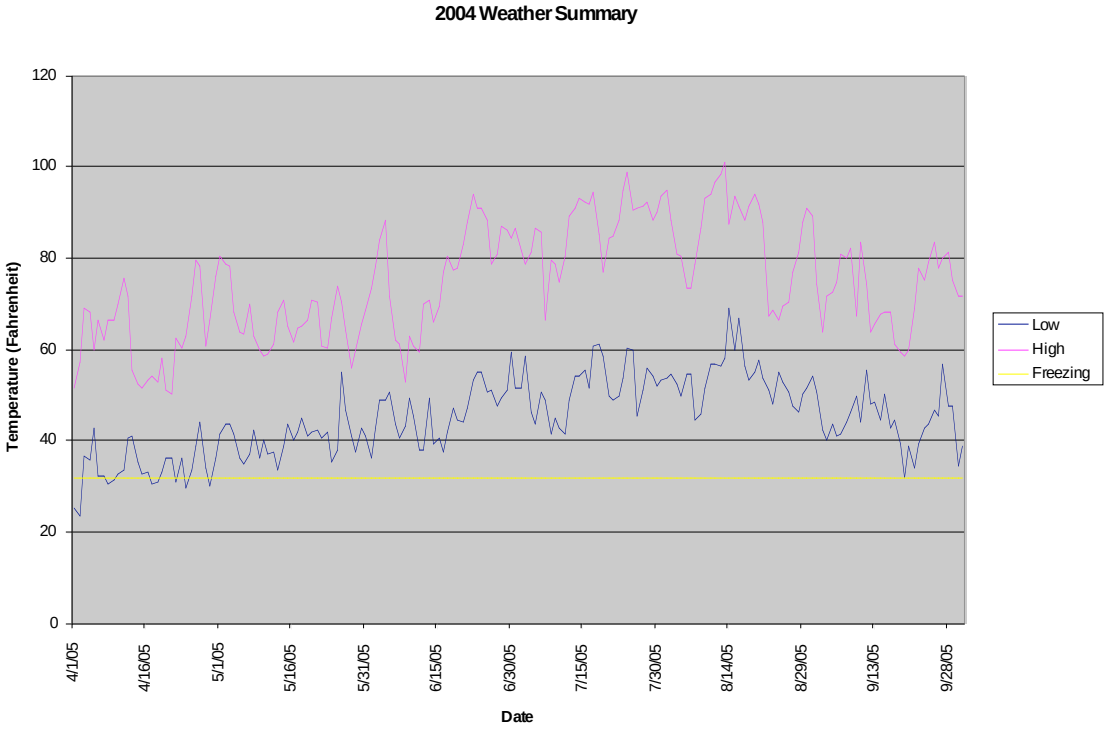


Figure 2. Air temperatures recorded at Central Oregon Agricultural Research Center, Madras, Oregon for years 2004 and 2005.



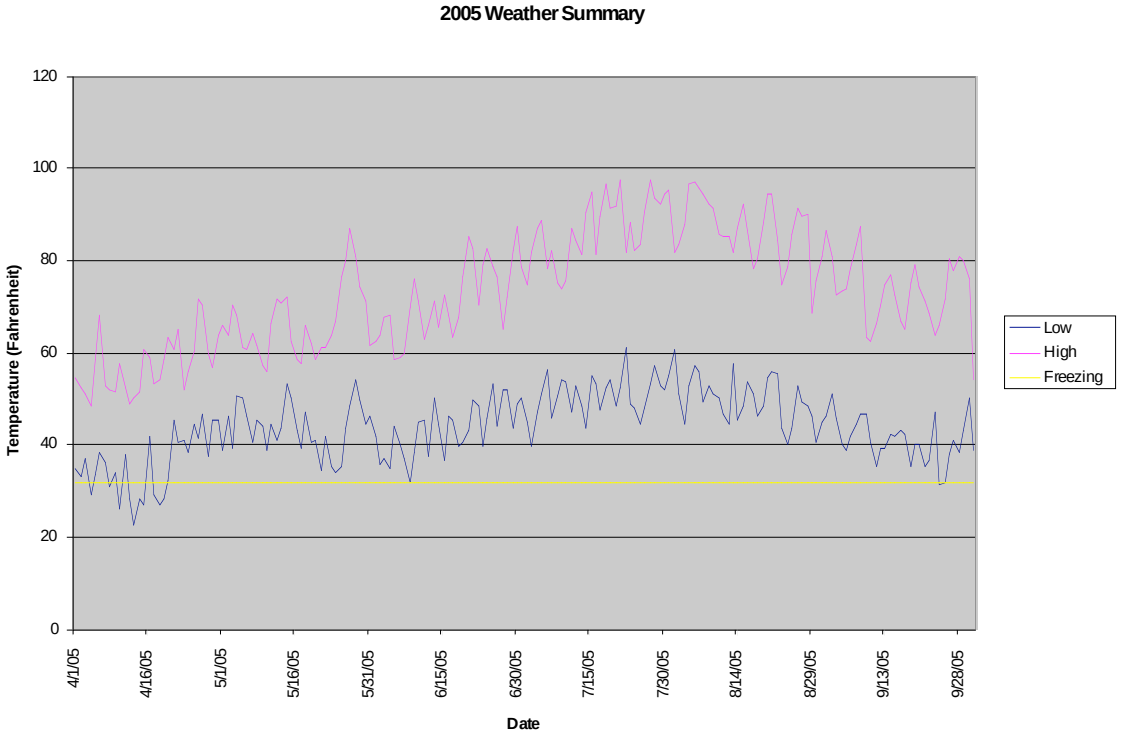


Figure 3. Seasonal incidence of plant infection by *Xanthomonas campestris* pv. *carotae* (XCC)(number of plants with XCC per 20 plants sampled) for different types of irrigation. Each field set included a drip- and a sprinkler-irrigated field planted with the same variety of carrots and within a common sub region of central Oregon, 2004.

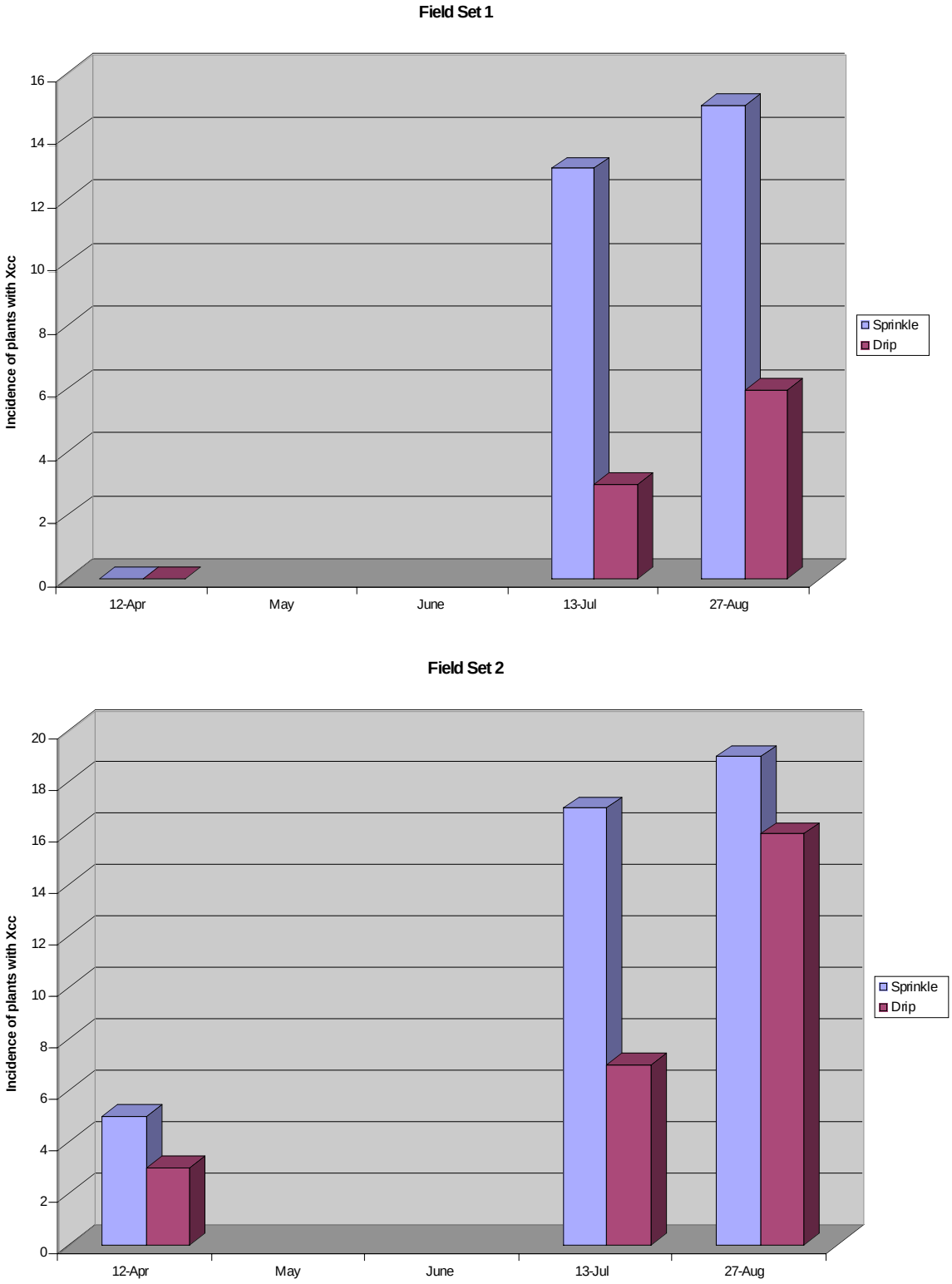
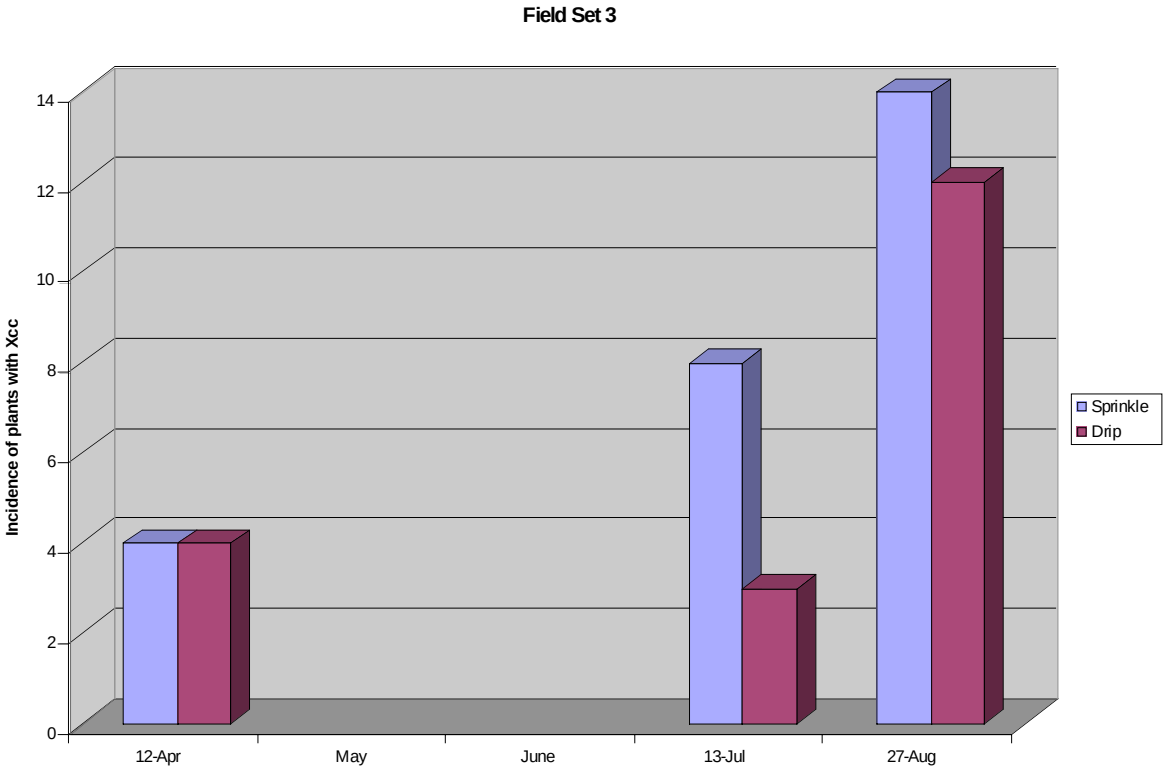


Figure 3. cont.



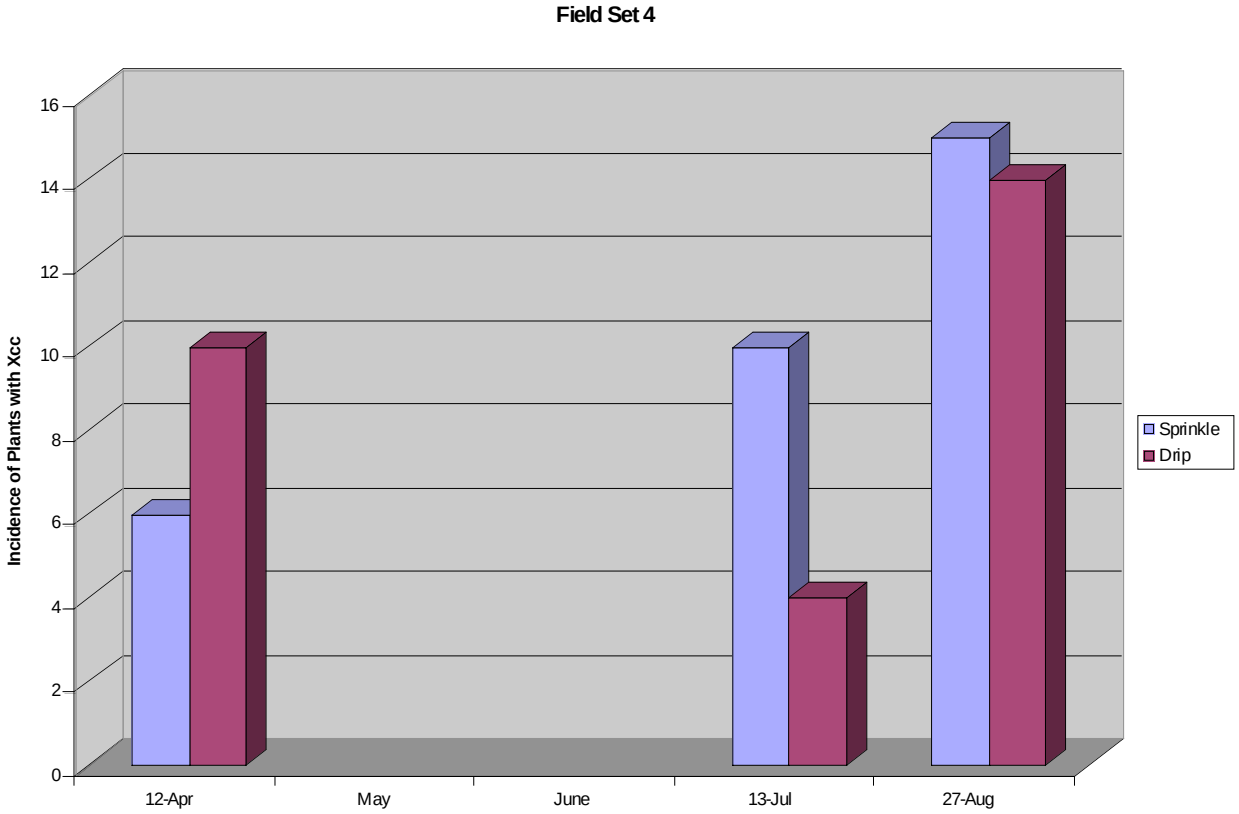


Fig. 3. cont.

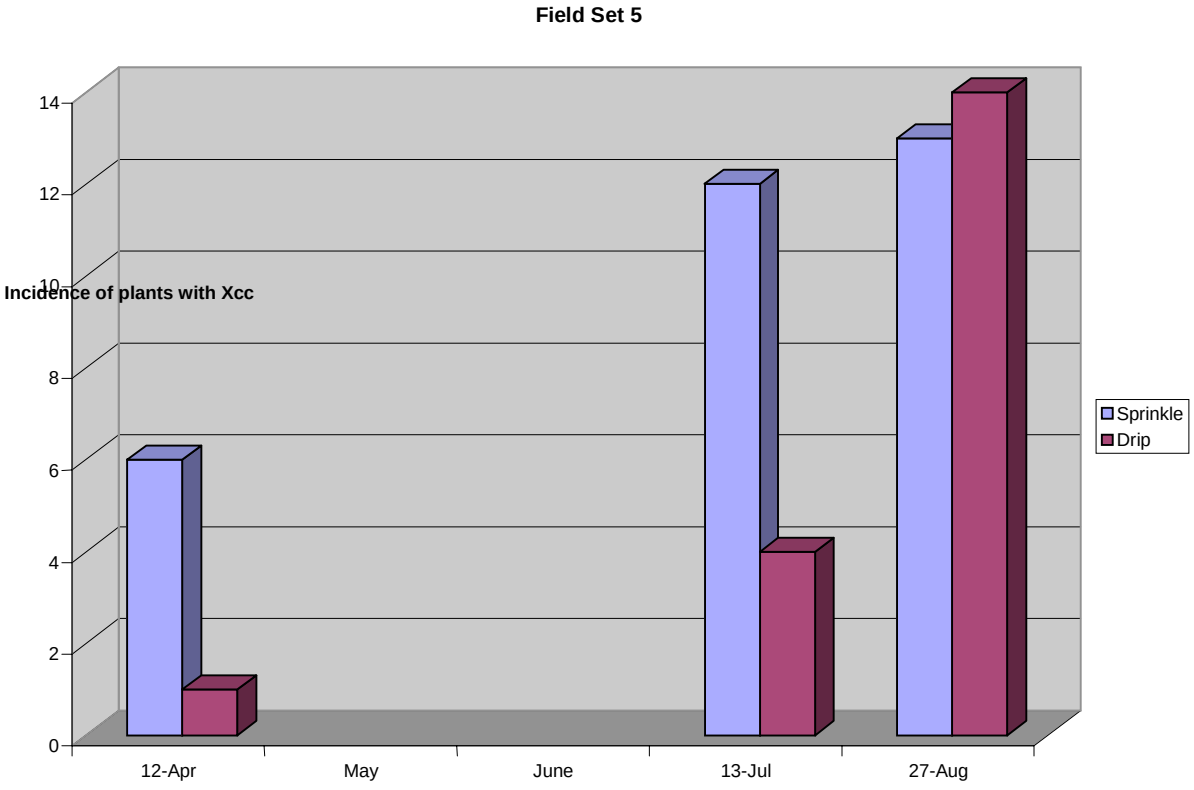

Field Set 5
Incidence of plants with Xcc
14
12
10
8
6
4
2
0
12-Apr
May
June
13-Jul
27-Aug
Sprinkle
Drip

Figure 4. Mean proportion of carrot plants infested with *Xanthomonas campestris* pv. *carotae* (XCC) in drip- vs. sprinkler-irrigated fields in central Oregon, 2004. Means labeled with different letters are statistically significant ($P < 0.05$).

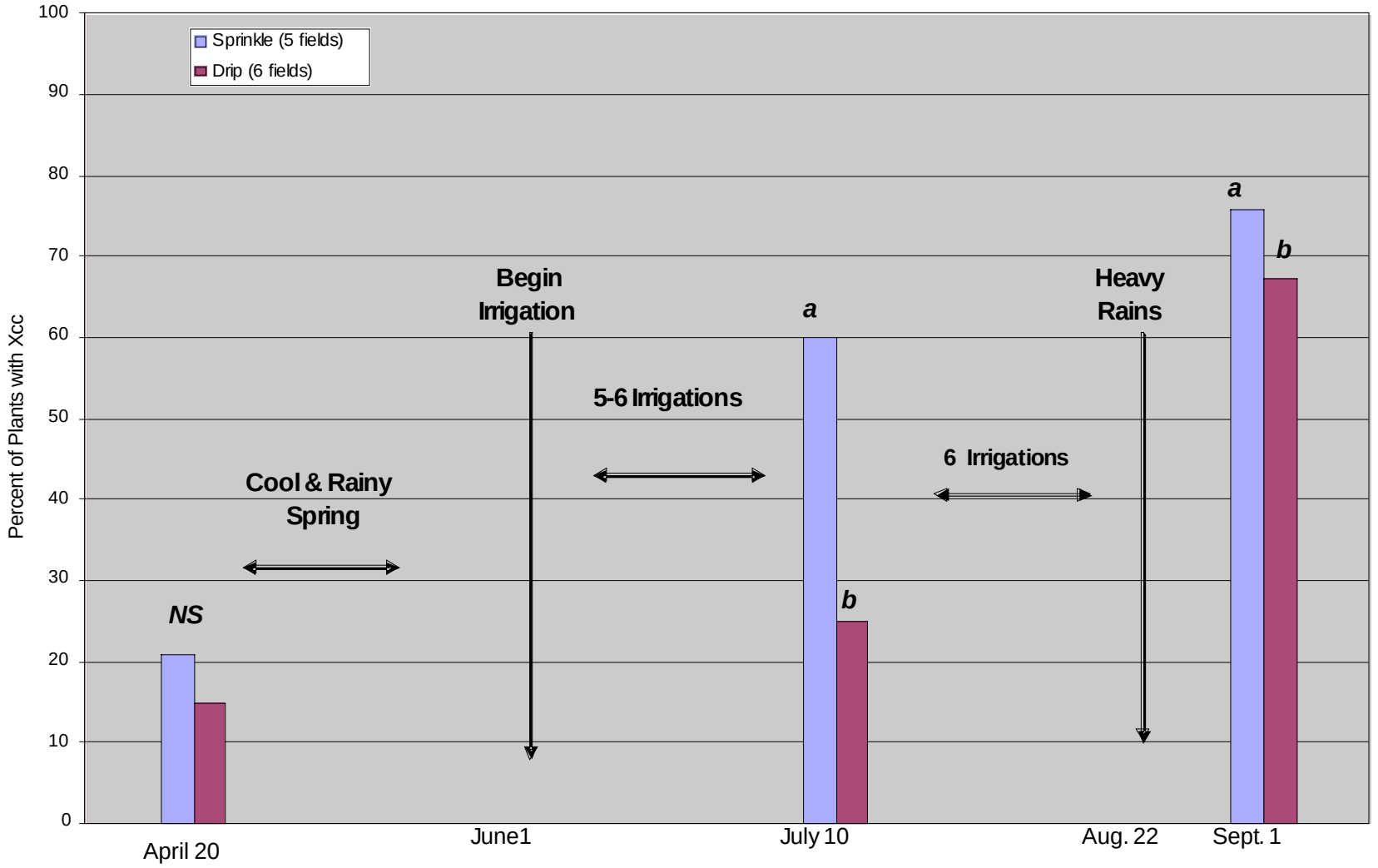


Figure 5. *Xanthomonas campestris* pv *carotae* recovered from harvested seed from drip- vs. sprinkler-irrigated fields in central Oregon, 2004. Means with different letters are statistically significant ($P < 0.05$).

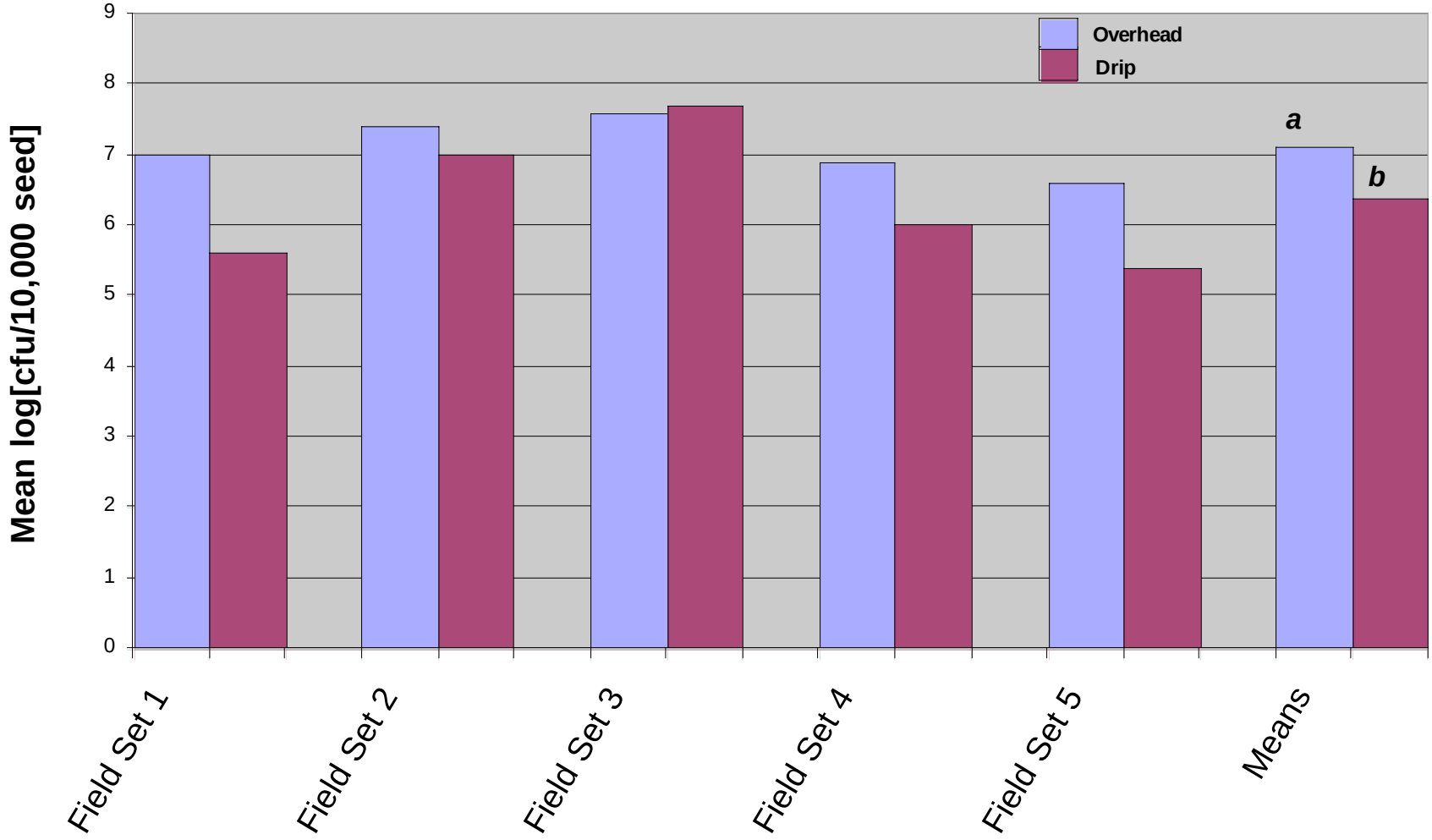
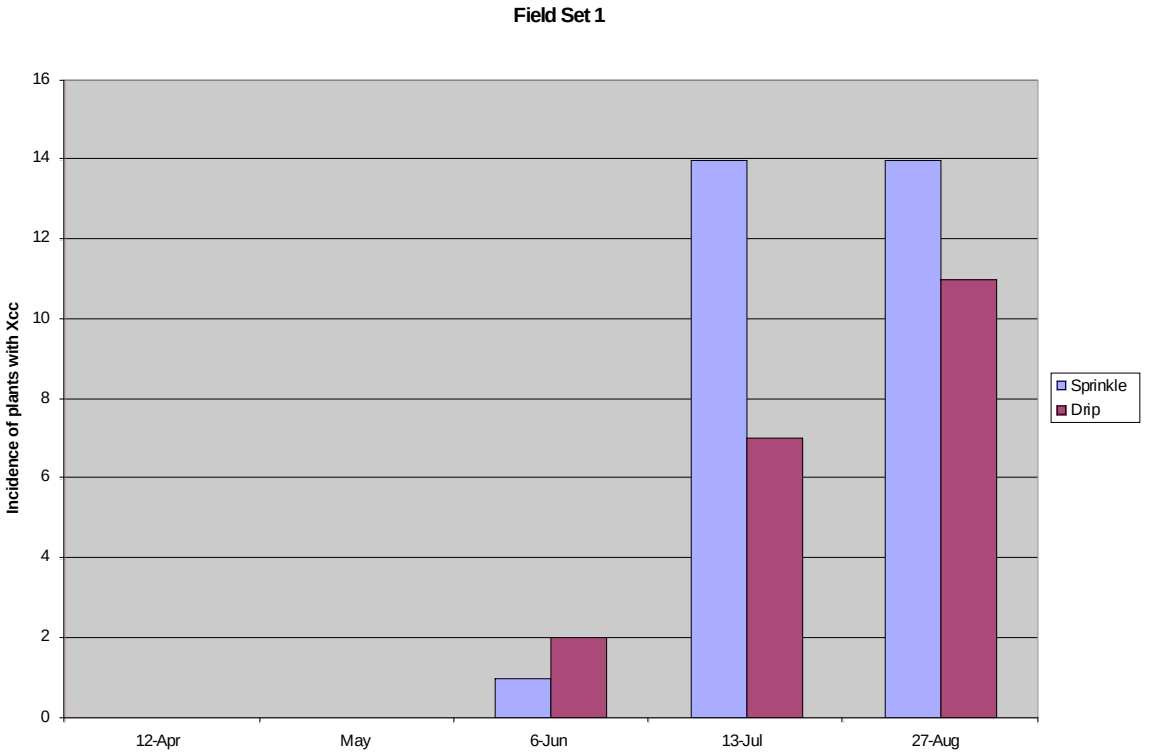


Figure 6. Seasonal incidence of plant infection by *Xanthomonas campestris* pv. *carotae* (XCC)(number of plants with XCC per 20 plants sampled) for different types of irrigation. Each field set included two fields planted with the same variety of carrots and within a common sub region of central Oregon, 2005.



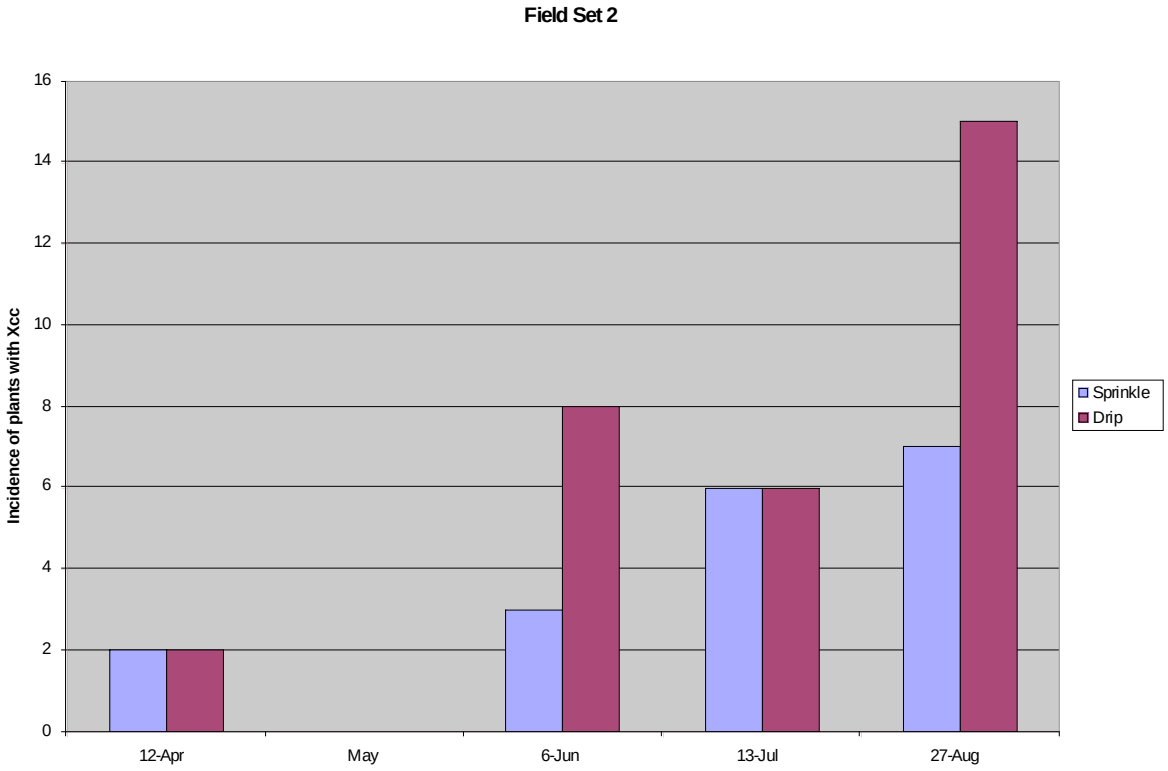
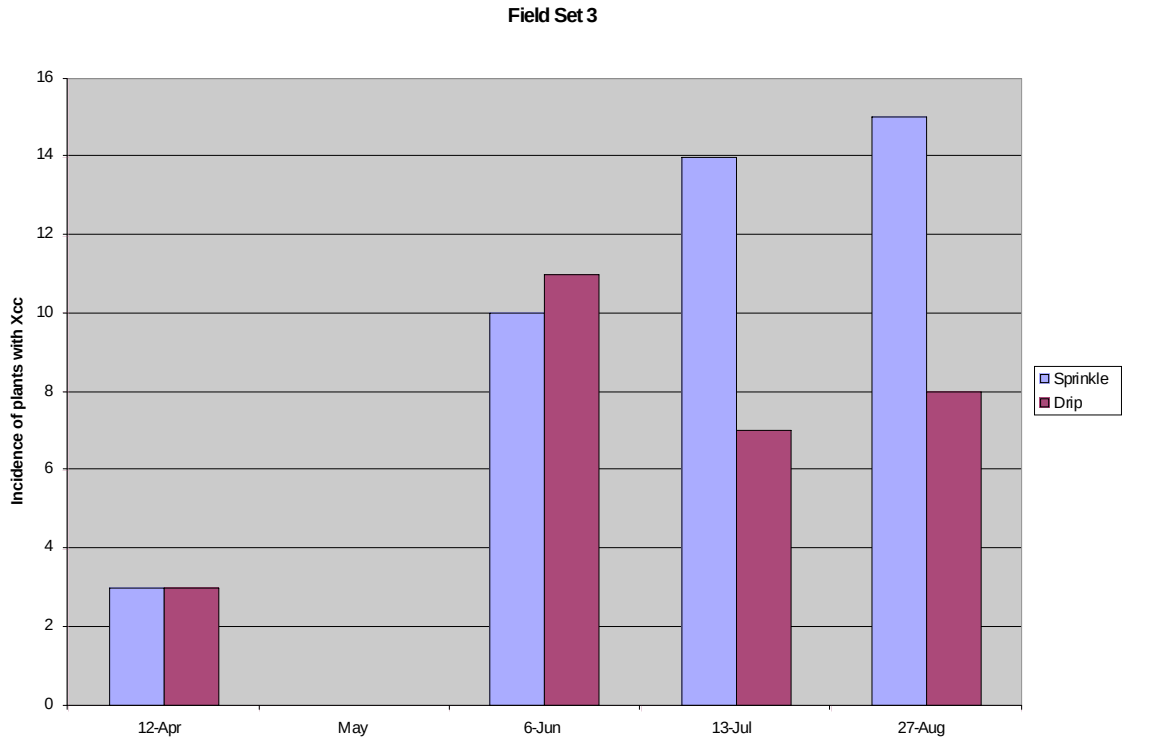


Figure 6. cont.



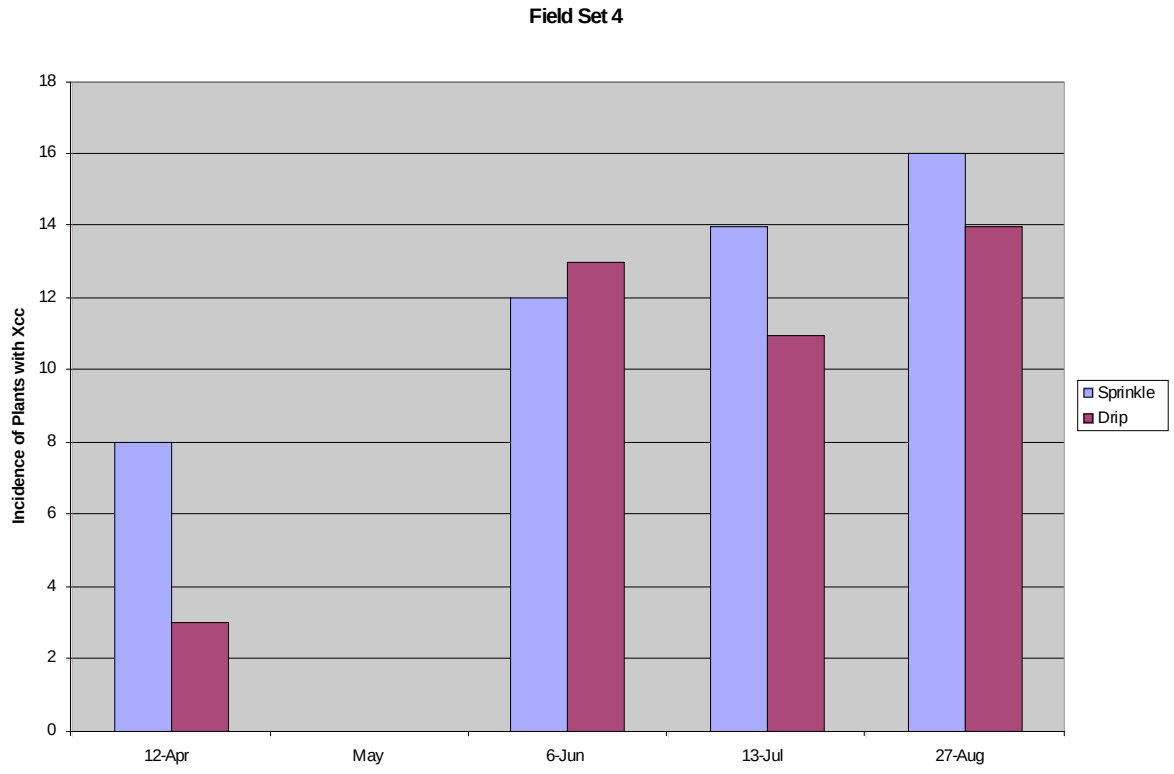
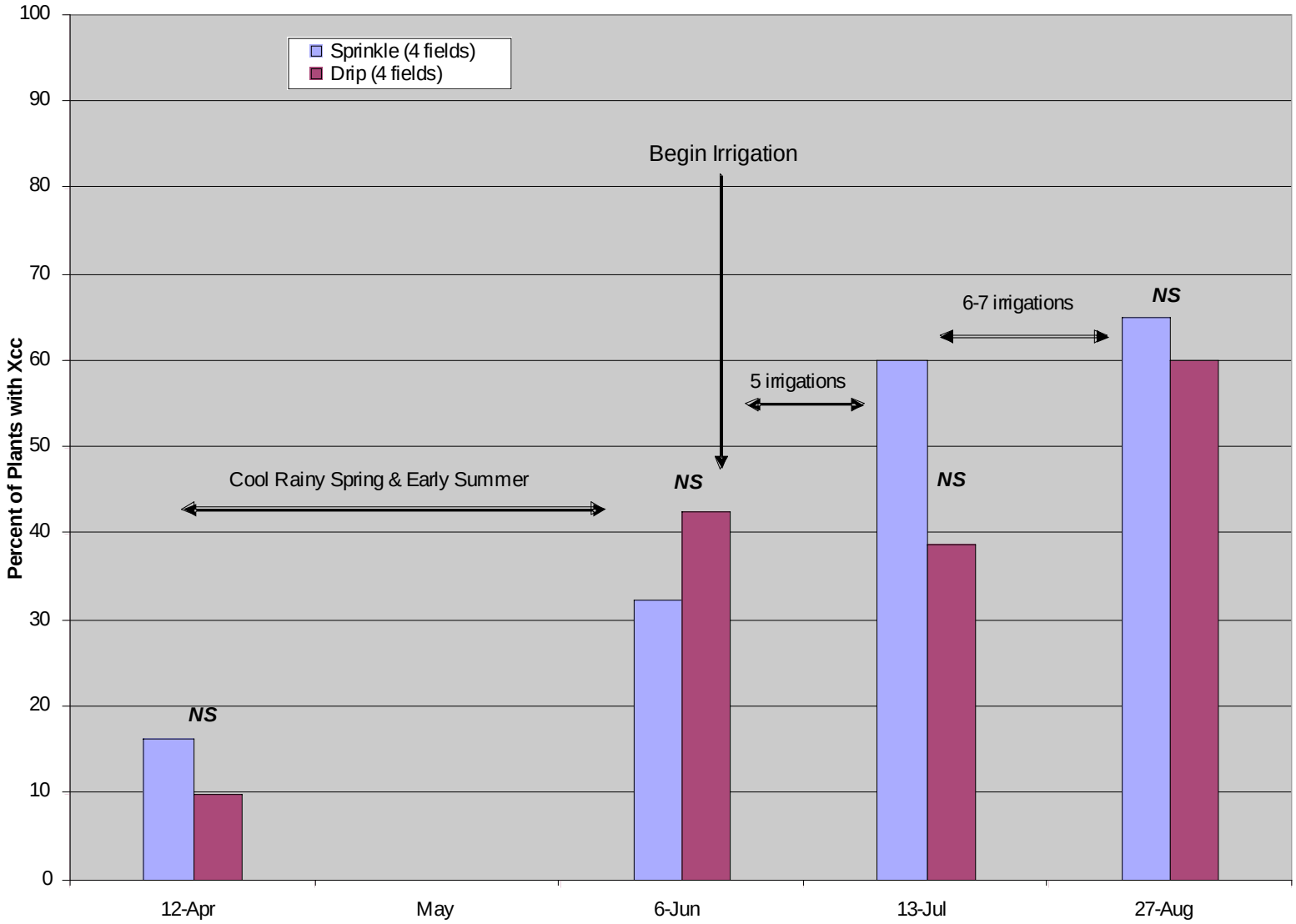


Figure 7. Mean proportions of carrot plants infected with *Xanthomonas campestris* pv. *carotae* (Xcc) in drip- vs. sprinkler-irrigated fields in central Oregon, 2005. Field sets labeled *NS* are not statistically significant ($P \leq 0.05$).



.

Figure 8. *Xanthomonas campestris* pv *carotae* recovered from harvested seed from drip- vs. sprinkler-irrigated fields in central Oregon, 2005. Means with different letters are statistically significant ($P < 0.05$).