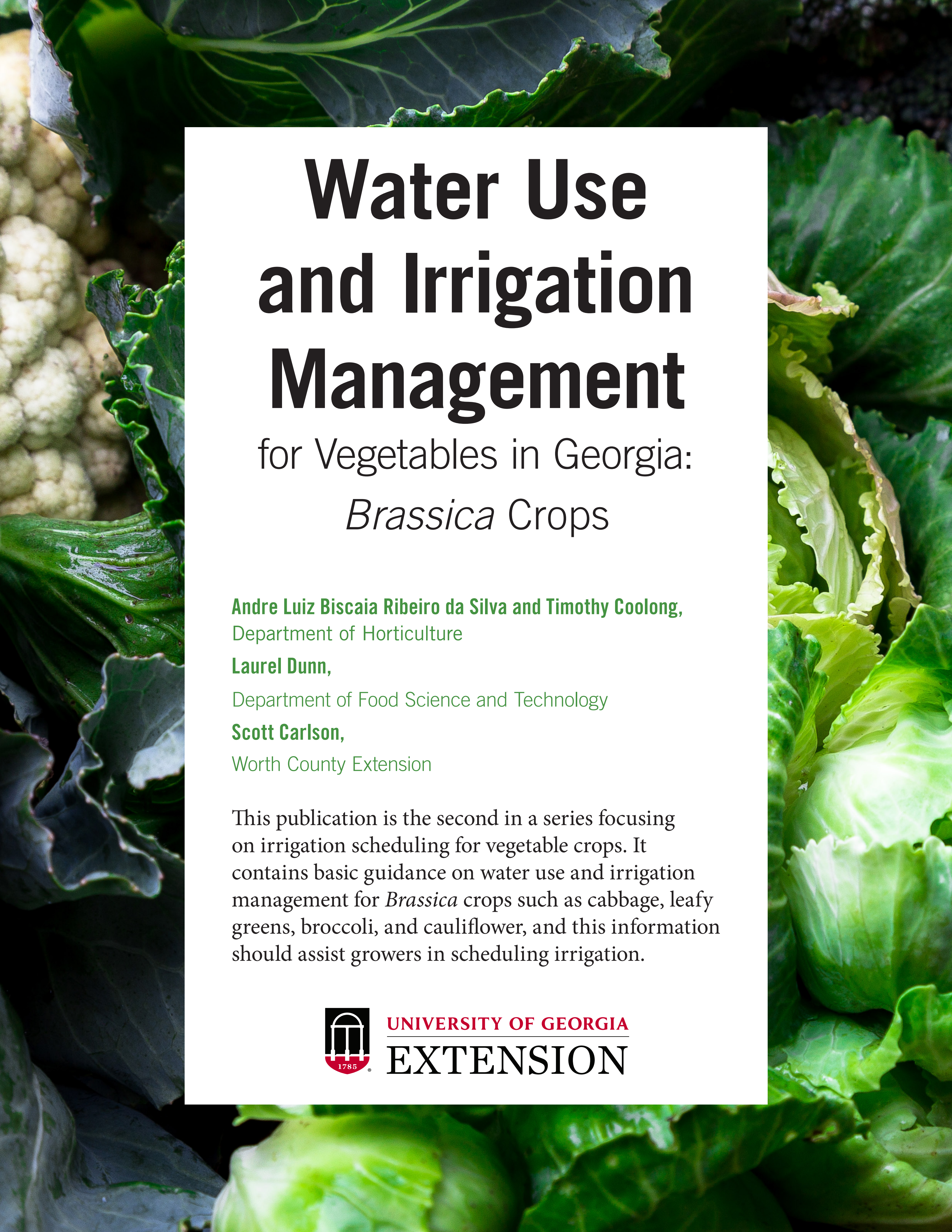

Water Use and Irrigation Management

for Vegetables in Georgia: *Brassica* Crops

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This publication is the second in a series focusing on irrigation scheduling for vegetable crops. It contains basic guidance on water use and irrigation management for *Brassica* crops such as cabbage, leafy greens, broccoli, and cauliflower, and this information should assist growers in scheduling irrigation.

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Irrigation scheduling

Although there are many strategies used to schedule irrigation, scheduling irrigation based on crop water demand is considered very effective for vegetable production (da Silva et al., 2019). The crop water demand method consists of determining irrigation water demand based upon daily crop evapotranspiration (ETc) of each growth stage of crop development. The ETc is calculated by multiplying the **daily reference evapotranspiration (ETo)** by a **crop coefficient (Kc)**. For a full description, see University of Georgia Cooperative Extension Bulletin 1511, "Principles of Irrigation and Scheduling for Vegetable Crops in Georgia." Daily ETo is available via the Georgia Automated Environmental Monitoring Network for many locations throughout Georgia, while the Kc of each stage of crop development have been previously estimated according to crop growth stages (Allen et al., 1998).

Daily reference evapotranspiration (ETo): The rate of water loss from a soil surface covered with a reference crop via vaporization

Crop coefficient (Kc): Plants' transpiration portion of ETc, which varies according to crop growth stages

For *Brassica* crops, the Kc is divided into initial ($Kc_{ini.}$; seedling stage), midseason ($Kc_{mid.}$) (growth stage), and end-season (Kc_{end}) (harvest stage) (Figure 1). The $Kc_{ini.}$ (0.7) is used from seed planting to the transplanting period, which occurs approximately three to four weeks after seeding, when plants are about 4 to 6 inches tall (Figures 2A and 3A). After transplanting, plants enter the vegetative growth stage, when leaf area grows (Figures 2B and 3B). In this stage, plants have a $Kc_{mid.}$ (1.05), which is the highest value observed in the crop production cycle. This period of high crop water demand can last up to 12 weeks after planting, and proper irrigation scheduling is critical to ensuring that a water deficit is not limiting yield. A week or two before harvesting, plant water demand is reduced (Figures 2C and 3C) and Kc_{end} (0.95) occurs.
This can be used to calculate the ETc for irrigation scheduling as the crop matures.

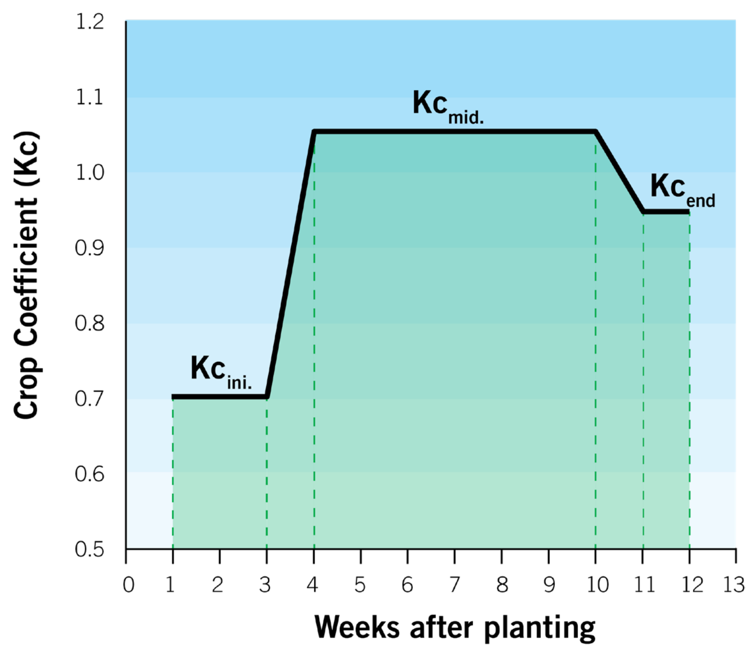

Figure 1. Crop Coefficient (Kc) for Brassica crops (cabbage, greens, broccoli, and cauliflower) during early season ($Kc_{ini.}$), mid-season ($Kc_{mid.}$), and end season (Kc_{end}) in weeks after planting.

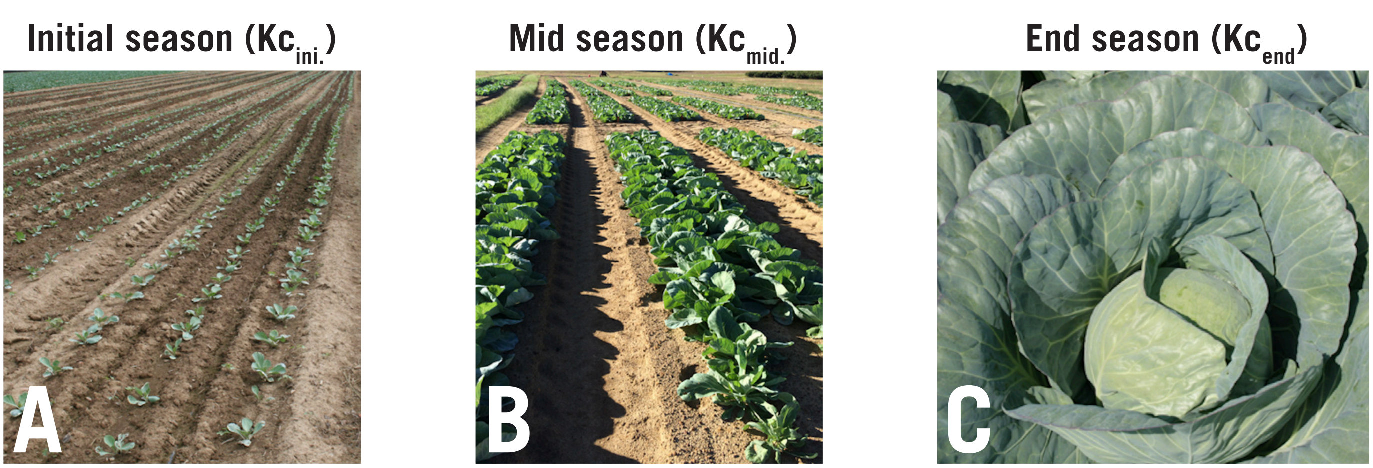

Figure 2. Crop coefficients (Kc) for cabbage growth stages.

Figure 3. Crop coefficients (Kc) for broccoli growth stages.

Determining an irrigation calendar

To determine a calendar-based irrigation schedule in Georgia, the crop water demand method was used for four planting dates in the spring and fall seasons of *Brassica* crops. Daily ETc from 2000 to 2017 was calculated using the daily ETo of eight different locations in southwest, southeast, northwest, and northeast Georgia (Figure 4).

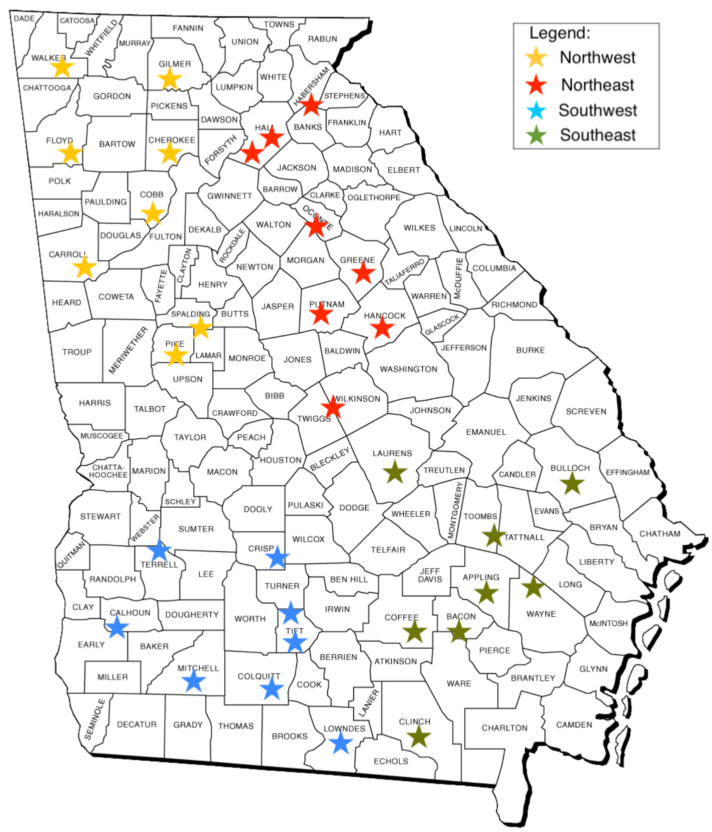

Figure 4. The locations of weather stations used to collect the historical weather data from each region of Georgia.

Spring growing season

In spring, weekly irrigation requirements for *Brassica* crops were determined for January 15, February 1 and 15, and March 1 planting dates. Figure 5 shows the average irrigation water demand per week among the four planting dates, while Table 1 has the irrigation water demand per week for each planting date in southwest, southeast, northwest, and northeast Georgia.

During the spring planting season, *Brassica* crops have a gradual increase in irrigation water demand as the crop matures. This is primarily due to a gradual increase in daily temperatures as spring progresses. Prior to the third week (after transplanting), *Brassica* crops are still 6 inches in height or less, and the crop water requirement is low. However, irrigation water demand rapidly increases beginning at 4 weeks after planting due to a drastic increase in leaf size (increase in Kc). Water stress after this point should be avoided to ensure crop growth and yield is fostered (Barrett et al., 2018). Irrigation water demand will only decrease at the end of the season (weeks 11 and 12). However, in late spring in Georgia, temperatures are already warm enough to quickly dry out the soil, and water application is still needed to avoid drought stress.

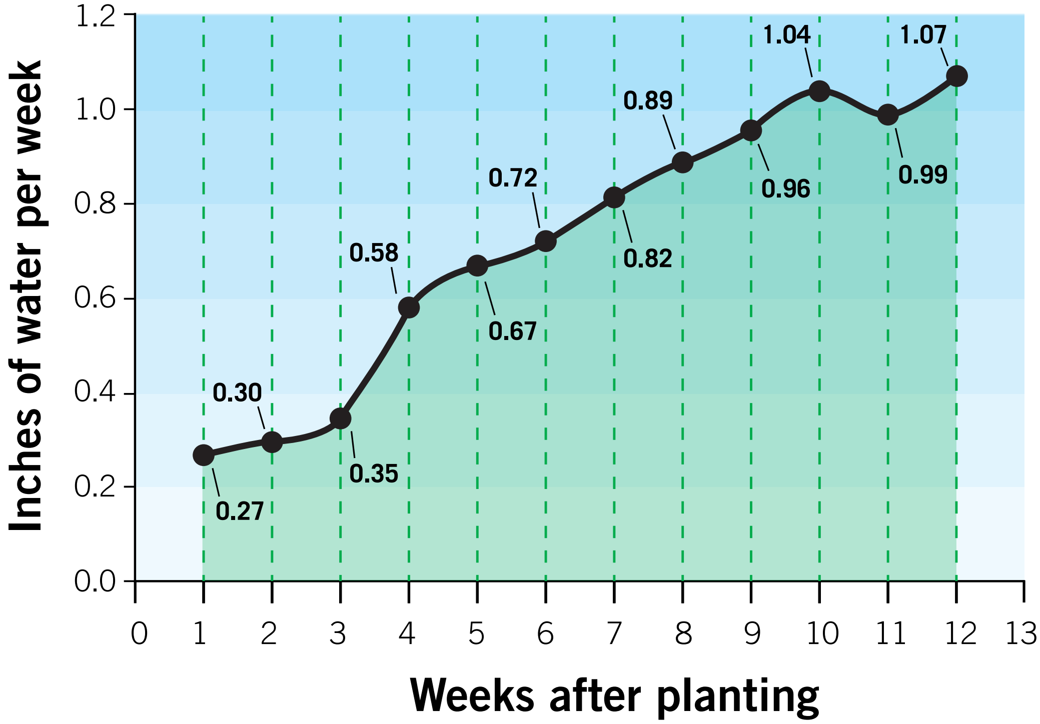

Figure 5. Average irrigation water demand in inches of water per week for *Brassica* crops (cabbage, broccoli, and cauliflower) grown during the **spring** season in Georgia. The average was calculated from a combination of 18 years of weather data (from 2000 to 2017), four different planting dates (e.g., January 15, February 1 and 15, and March 1), and 24 locations around Georgia.

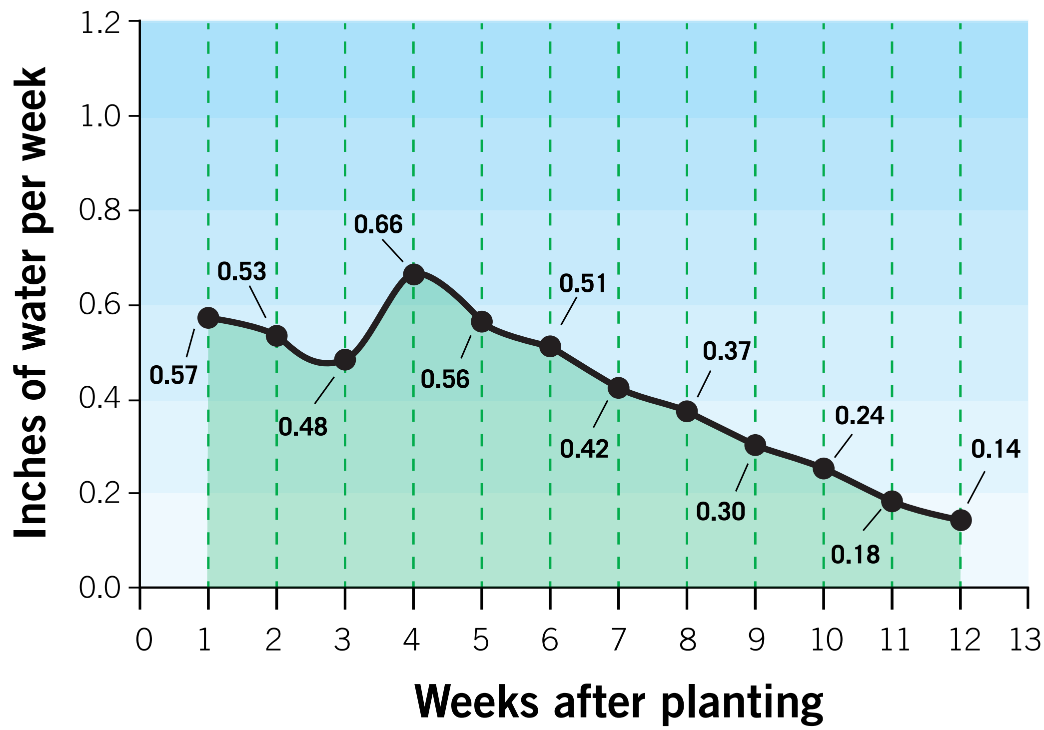

Figure 6. Average irrigation water demand in inches of water per week for *Brassica* crops (cabbage, broccoli, and cauliflower) grown during the **fall** season in Georgia. The average was calculated from a combination of 18 years of weather data (from 2000 to 2017), four different planting dates (e.g., August 15, September 1 and 15, and October 1), and 24 locations around Georgia.

Fall growing season

For fall crops, weekly irrigation requirements for *Brassica* crops were determined for August 15, September 1 and 15, and October 1 planting dates. Figure 6 shows the average irrigation water demand per week among the four planting dates, while Table 2 has the irrigation water demand per week for each planting date in southwest, southeast, northwest, and northeast Georgia.

Unlike the spring season, temperatures begin to decrease as the crop develops during the fall season. Consequently, irrigation water demand gradually decreases throughout the season, despite increasing plant size. Irrigation water demand is low in the beginning of fall season due to the low crop water demand required by smaller plants (weeks one to three). However, due to high temperatures and small root systems at planting, growers may find the need to irrigate more than required by the crop to ensure survival. At four weeks after planting, there is still a peak in the irrigation water demand caused by the increase in leaf area expansion (Paranhos et al., 2016). From four to 11 weeks after planting, *Brassica* crops in this growth stage are most sensitive to water stress (Barrett et al., 2018). Although crop water requirements are the highest, irrigation water demand gradually declines due to cooler temperatures. Eleven weeks after planting, crop water requirements decrease and growers should reduce irrigation water to avoid incidences of black rot, alternaria, sclerotinia, and other diseases.

Food safety considerations

When growing *Brassica* crops on a farm covered by the Produce Safety Rule (PSR), irrigation water must meet microbial water quality standards. Irrigation water that will contact the harvestable portion of the crop **may not contain generic *E. coli* levels that exceed:**

1. **A geometric mean (GM) of 126 colony forming units (CFU; 2.1 log CFU/mL) per 100 mL of water, or**
2. **A statistical threshold value (STV) of 410 CFU (2.61 log CFU/mL) per 100 mL of water**

If water used for irrigation exceeds the criteria, growers must allow sufficient time for microbial die-off in the field or after harvest. The PSR assumes a die-off rate of 0.5 log per day for no more than four consecutive days. For example, if the GM of water contacting the crop is 356 CFU/mL (2.54 log CFU/mL) and the STV is 938 CFU/mL (2.97 log CFU/mL), a one-day die-off period should result in a 0.5 log CFU/mL reduction, returning the GM and STV thresholds to below PSR requirements. Another option is to divert the crop to a processor that will apply a “kill” step (e.g., cooking). Water treatment must be considered when microbial water quality is above allowable levels (U.S. Food and Drug Administration, 2015). Chemigation by chlorine or peroxyacetic acid may be used to treat production water, but plant and soil health should be considered if using either sanitizer for extended periods of time.

Summary

The volume of water required in each growing season depends more on the planting date than the location within the state. This is to be expected since ETc is related to weather variables like temperature, solar radiation, relative humidity, and wind speed (Allen et al., 1998). Growers who delay the planting date of *Brassica* crops in the spring season will need to apply higher volumes of irrigation compared to growers planting early in the season (Table 1). Conversely, late planting dates in fall require less water compared to early planting dates (Table 2). For example, a grower in southwest Georgia who plants on January 15 will require 5 inches less water during the spring season than a grower who plants on March 1. A grower in southwest Georgia who plants on August 15 will require 4.4 more inches of water during the fall season compared to a grower whose planting date is October 1.

Irrigation water demand reported in Tables 1 and 2 can be used for irrigation scheduling, but this scheduling is best managed when combined with the monitoring of soil moisture. Weather conditions should be considered to avoid over- or under-irrigation. For example, growers under bare soils (not using plasticulture) should account for rainfall events in irrigation scheduling, otherwise, plants could be overwatered. The efficiency of irrigation systems' water delivery should also be considered before water application. More information about *Brassica* crop production can be found in UGA Cooperative Bulletin 1181, "Commercial Production and Management of Cabbage and Leafy Greens" and in UGA Extension Bulletin 1460, "Fresh Market Broccoli Production for Georgia."

Table 1. Historical irrigation water demand per week for *Brassica* crops on four planting dates (January 15, February 1 and 15, and March 1) in the spring season of southwest, southeast, northwest, and northeast Georgia.

Week after planting	Southwest				Southeast				Northwest				Northeast			
	1/15	2/1	2/15	3/1	1/15	2/1	2/15	3/1	1/15	2/1	2/15	3/1	1/15	2/1	2/15	3/1
	inches of water per week															
1	0.19	0.24	0.35	0.44	0.17	0.22	0.32	0.40	0.13	0.18	0.25	0.35	0.11	0.18	0.35	0.44
2	0.22	0.29	0.35	0.49	0.19	0.26	0.32	0.45	0.13	0.21	0.28	0.38	0.16	0.22	0.38	0.46
3	0.24	0.35	0.44	0.54	0.22	0.32	0.40	0.48	0.18	0.25	0.35	0.44	0.18	0.27	0.44	0.55
4	0.44	0.53	0.74	0.87	0.39	0.48	0.67	0.78	0.32	0.42	0.56	0.70	0.33	0.38	0.69	0.91
5	0.53	0.66	0.81	0.99	0.48	0.59	0.72	0.90	0.38	0.53	0.66	0.81	0.40	0.53	0.83	0.95
6	0.53	0.74	0.87	1.06	0.48	0.67	0.78	0.99	0.42	0.56	0.70	0.87	0.38	0.57	0.91	1.05
7	0.66	0.81	0.99	1.16	0.59	0.72	0.90	1.04	0.53	0.66	0.81	1.01	0.53	0.66	0.95	1.09
8	0.74	0.87	1.06	1.24	0.67	0.78	0.99	1.13	0.56	0.70	0.87	1.04	0.57	0.69	1.05	1.21
9	0.81	0.99	1.16	1.29	0.72	0.90	1.04	1.18	0.66	0.81	1.01	1.08	0.66	0.83	1.09	1.13
10	0.87	1.06	1.24	1.41	0.78	0.99	1.13	1.31	0.70	0.87	1.04	1.19	0.69	0.91	1.21	1.32
11	0.89	1.05	1.16	1.26	0.82	0.94	1.07	1.12	0.74	0.91	0.98	1.05	0.75	0.86	1.02	1.14
12	0.96	1.12	1.27	1.36	0.89	1.03	1.18	1.24	0.79	0.94	1.07	1.20	0.83	0.95	1.20	1.14
Total	**7.1**	**8.7**	**10.4**	**12.1**	**6.4**	**7.9**	**9.5**	**11.0**	**5.5**	**7.1**	**8.6**	**10.1**	**5.6**	**7.1**	**10.1**	**11.4**

Table 2. Historical irrigation water demand per week for *Brassica* crops on four planting dates (August 15, September 1 and 15, and October 1) in the fall season of southwest, southeast, northwest, and northeast Georgia.

Week after planting	Southwest				Southeast				Northwest				Northeast			
	8/15	9/1	9/15	10/1	8/15	9/1	9/15	10/1	8/15	9/1	9/15	10/1	8/15	9/1	9/15	10/1
	inches of water per week															
1	0.77	0.72	0.58	0.47	0.70	0.66	0.54	0.42	0.66	0.61	0.50	0.37	0.68	0.60	0.48	0.37
2	0.73	0.64	0.54	0.46	0.67	0.59	0.48	0.42	0.64	0.55	0.45	0.35	0.66	0.55	0.45	0.36
3	0.72	0.59	0.47	0.37	0.66	0.54	0.42	0.35	0.61	0.50	0.37	0.28	0.60	0.48	0.37	0.28
4	0.97	0.81	0.69	0.51	0.89	0.72	0.63	0.45	0.83	0.68	0.53	0.37	0.82	0.68	0.54	0.37
5	0.89	0.71	0.56	0.41	0.81	0.64	0.52	0.36	0.75	0.56	0.42	0.30	0.72	0.56	0.43	0.30
6	0.81	0.69	0.51	0.34	0.72	0.63	0.45	0.31	0.68	0.53	0.37	0.24	0.68	0.54	0.37	0.25
7	0.71	0.56	0.41	0.29	0.64	0.52	0.36	0.26	0.56	0.42	0.30	0.19	0.56	0.43	0.30	0.19
8	0.69	0.51	0.34	0.24	0.63	0.45	0.31	0.21	0.53	0.37	0.24	0.14	0.54	0.37	0.25	0.14
9	0.56	0.41	0.29	0.18	0.52	0.36	0.26	0.16	0.42	0.30	0.19	0.11	0.43	0.30	0.19	0.11
10	0.51	0.34	0.24	0.15	0.45	0.31	0.21	0.13	0.37	0.24	0.14	0.08	0.37	0.25	0.14	0.08
11	0.37	0.26	0.16	0.09	0.33	0.23	0.14	0.08	0.27	0.17	0.10	0.04	0.27	0.18	0.10	0.04
12	0.31	0.21	0.14	0.07	0.28	0.19	0.12	0.06	0.22	0.13	0.07	0.02	0.22	0.13	0.07	0.07
Total	**8.0**	**6.5**	**4.9**	**3.6**	**7.3**	**5.8**	**4.4**	**3.2**	**6.5**	**5.1**	**3.7**	**2.5**	**6.6**	**5.1**	**3.7**	**2.6**

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