Research Reports

Cost-benefit Analysis of Cabbage Grown Using a Plasticulture and Seepage Bare Ground Production System in Florida

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SUMMARY. Seepage is characterized as an inefficient irrigation method with regard to water and nutrient use. There is a need for an economically viable irrigation alternative to seepage, which increases crop productivity and profitability in Florida. The use of plastic mulch and drip irrigation for cabbage (*Brassica oleracea* var. *capitata*) production increases plant population per area and reduces the irrigation water requirement. However, plasticulture has a high capital investment and operating cost. The objectives of this study were to compare the profitability of plasticulture cabbage production and traditional seepage bare ground irrigation systems for Florida cabbage production, and to determine the breakeven point for cabbage grown under plasticulture given a range of market prices. The preharvest cost per acre for the plasticulture system was significantly higher than the cost for the seepage system (\$4726 and \$3035 per acre, respectively). However, for all planting dates considered in this study, the plasticulture system resulted in a significant increase in marketable yields when compared with the seepage system. The resulting increase in potential revenue offset the increase in preharvest costs and assured a positive net return on investment over the whole range market prices. It was also observed that low air temperatures combined with reduced solar radiation can prevent optimum plant development for cabbage transplanted between November and mid-December. Therefore, the return on investment may be reduced during less favorable climatic conditions for cabbage growth, making the plasticulture system less economically desirable for certain planting dates.

Although the success of plasticulture for several high-value horticultural crops has been documented (Borosis et al., 1998; Shrivastava et al., 1994; Tiwari et al., 1998), commercial cabbage production in Florida still relies on a bare ground system with seepage irrigation, primarily due to this system's low cost of operation and the ease of management (Locascio, 2005). The utilization of plasticulture for cabbage production is a possible alternative to the traditional bare ground with seepage irrigation, potentially allowing for reduction in water withdrawals and pollution runoff in environmentally sensitive areas according to the Florida Department of Agriculture and Consumer Services (FDACS, 2015). Plasticulture increases the efficiency of water and fertilizer use (Shukla et al., 2014), potentially reducing the impacts of the agricultural production on the water source and downstream water quality. Conversely, the major disadvantages of the plasticulture system include the removal and disposal of the plastic and drip tubing, increase in management since drip irrigation generally requires daily monitoring, and greater initial costs compared with the bare ground system (Goyal, 2013). However, to increase the adoption rate among Florida producers, farmers should have access to information about the economic feasibility of the system in comparison with the traditional production practices. Currently, limited information exists on the cost and profitability of a plasticulture system for cabbage production. Past studies focused on different horticultural crops and were conducted in regions with different production conditions than those common to Florida. For example, Pitts et al. (1989) and Prevatt et al. (1992) found a significant cost increase for drip compared with seepage irrigation for Florida tomato (*Solanum*

Plastic mulch in combination with drip irrigation is widely used for vegetable production in Florida (Locascio, 2005). The benefits associated with this plasticulture system in comparison with the traditional bare ground seepage irrigation include earlier and higher marketable yield, reduced weed pressure, higher irrigation efficiency, protection of fertilizer/enhanced fertilizer efficiency, and the ability to double or triple crop on the same plastic (Lamont, 1993).

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
45.3592	cwt	kg	0.0220
112.0851	cwt/acre	kg·ha ⁻¹	0.0089
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
0.0254	mil	mm	39.3701
6.8948	psi	kPa	0.1450
2.2417	ton(s)/acre	Mg·ha ⁻¹	0.4461
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

lycopersicum) production with no significant yield increase to offset the increase in the costs. Conversely, Vavrina and Roka (2000) and Simonne et al. (2002) compared costs and returns for plasticulture with bare ground for onion (*Allium cepa*) and okra (*Abelmoschus esculentus*), respectively. Both studies showed that plasticulture could be an economically feasible option for these crops in Florida, since increased yields and returns outweighed the higher production costs. Tiwari et al. (2003), showed a net income of \$4333/ha for plasticulture in India, which was 40% higher than what was reported for bare ground with furrow irrigation. Although those results were promising, the soil conditions, plant spacing, and market requirements for cabbage in that study were considerably different from Florida's, reducing the applicability of their findings to address concerns in Florida.

Plasticulture requires a high initial capital investment, which can be a barrier for adoption by vegetable producers. Therefore, the adoption of plasticulture in cabbage production will depend on the ability of this system to increase marketable yield enough to offset the higher production costs, or the availability of a cost-share program to balance the increased cost. Accurate information about the costs and benefits of the plasticulture system is critical for outreach programs aimed at educating producers about more economically feasible and environmentally sustainable production practices. The information is also important to determine if a cost-share program should be established to incentivize and compensate producers for

the extra expenses incurred with the plasticulture system.

Barrett et al. (2015) proposed an innovative plasticulture system for high plant population cabbage production in Florida and Paranhos et al. (2016) examined yield variability of this new system as function of different transplanting dates. In both studies, cabbage marketable yield ranged from 42 to 70 Mg·ha⁻¹. These marketable yields were considerably higher than the 340 cwt/acre average reported for bare ground and seepage irrigation according to the U.S. Department of Agriculture (USDA, 2015), indicating that plasticulture has the potential to increase revenue and sufficiently offset the costs.

The objectives of this study were to compare the profitability of plasticulture cabbage production and traditional seepage irrigation systems for Florida cabbage production, and to determine the breakeven point for cabbage grown using plasticulture given a range of market prices.

Material and methods

PRODUCTION EXPERIMENTS. Plasticulture production experiments were conducted at the University of Florida, Hastings Agricultural Extension Center in Hastings, FL (lat. 29°69'N, long. 81°44'W), from Sept. to Apr. in 2013–14 and 2014–15. The material and methods associated with the field trials are described in detail in Paranhos et al. (2016). The soil at the research site was characterized as a Placid fine sand: sandy, siliceous, hyperthermic, typic, humaquepts (Readle, 1983). 'Bravo' cabbage was transplanted on 17 Sept. (SEP), 11 Oct. (OCT), 7 Nov. (NOV), and 3 Dec. (DEC) of 2013 and 16 Sept., 9 Oct., 4 Nov., and 2 Dec. of 2014. Cabbage was grown on 48-inch-wide raised beds spaced 80 inches on center with black plastic mulch [72 inches wide, 1.25 mil thick (VIF film; Polygro, Safety Harbor, FL)]. Two drip tapes spaced 2 ft apart [5/8 inch diameter, 12-inch emitter spacing, 0.13 gal/h at 8 psi (Aqua-Traxx model EA5081222; Toro Agricultural Irrigation, El Cajon, CA)]. A tractor-mounted hole puncher was used to make four rows of planting holes with an in-row spacing of 12 inches. The plant population was 26,136 plants/acre. Plots were 35 ft long. A granular fertilizer mix of 10N–6.6P–8.3K was incorporated into beds preplant at a rate of 2272 lb/acre providing 227 lb/acre nitrogen (N),

149 lb/acre phosphorus (P), and 189 lb/acre potassium (K). The preplant fertilizer supplied 42%, 100%, and 42% of the total N, P, and K, respectively. A total of 140 lb/acre N and 96 lb/acre K were applied in four split applications by fertigation through the drip tape.

Marketable yield was recorded for each planting date from the 2013–14 and 2014–15 seasons. The mean marketable yield and standard error for each planting date were used for this analysis. The correlation between marketable yield and air temperature reported by Paranhos et al. (2016) was used to estimate average cabbage marketable yield as a function of historic air temperature for northeast Florida cabbage production area, more specifically Putnam County. Sixty-four years of air temperature and solar radiation obtained from the National Weather Service Cooperative Observer Program (COOP) weather station located in Federal Point, FL (COOP_ID 82915), were used to calculate the mean and standard deviation for air temperature of 100 consecutive days (approximate length of crop season from transplant to harvest) beginning at day 240 of the year (5 Sept.) and extending to the day 360 (26 Dec.). The Florida marketable yield for bare ground production was estimated using the USDA database for 2011–14 (USDA, 2015).

ECONOMIC ANALYSES. A partial budget analysis was used to analyze changes in profits associated with incremental changes in specific inputs or practices. A partial budget analysis was used to compare profits between the bare ground with seepage and the plastic mulch with drip irrigation (plasticulture) systems.

The costs of the bare ground cabbage production system for the northeast Florida region were based on the University of Florida Institute of Food and Agricultural Sciences production budget (VanSickle, 2008) that was updated with current market prices. Specifically, transplants costs were updated to reflect 2015 prices provided by Speedling Inc. (Ruskin, FL). Fertilizer and fumigant costs were based on current prices from local suppliers for the northeast Florida region (Diamond R, Palatka, FL and TriEst Ag Group, Palmetto, FL).

The capital investment cost required to convert a bare ground production system with seepage irrigation to the plasticulture system was

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based on the production experiment expenses. For the fixed costs, equipment depreciation costs were calculated using a straight-line depreciation method based on the expected lifespan of the equipment and assuming zero salvage costs. Plastic mulch, drip tape, irrigation fittings, and polyethylene pipe costs plus the additional labor (2 h/acre) for plastic mulch and drip tape installation were included into the plasticulture budget. The labor wage used for all labor costs was based on the 2014 average wage for an entry-level farm worker in the state of Florida of \$8.49/h using data from the occupational employment and wage survey conducted by the U.S. Department of Labor and Labor Market Information (Florida Department of Economic Opportunity, 2015). The additional costs from the use of a much higher plant population under plasticulture were accounted for as the increase in transplants and the labor required for transplanting. The costs of transplants were based on \$0.02/plant. Labor required for transplanting additional plants was estimated from repeated trials and on-farm demonstrations at 6.6 h/acre. Fertilizer costs for the plasticulture system were based on the increased plant population, assuming the rate of fertilizer application per plant remains the same for seepage and plasticulture system (i.e., a conservative assumption). The costs of herbicides, insecticides, fungicides, and equipment operating costs were considered the same for both the plasticulture and seepage systems because these costs are estimated on an area basis.

Net returns for the plasticulture and bare ground systems were estimated by subtracting the preharvest production costs from the estimated return per acre. Note that preharvest costs account for the majority (61.2%) of cabbage production costs (VanSickle, 2008), and they are often used by producers to decide about the adoption of new production methods. Although the increased planting density and yield for plasticulture will likely increase the cutting, hauling, packing, and selling costs, the relation between the harvest volume and harvesting and sale costs is nonlinear. For example, for producers selling on spot market, harvesting can be halted when the sale price drops below a profitable value, allowing producers to avoid harvesting costs. In turn, for the producers under

contracts, increased sale volumes and potentially expanded duration of harvesting and sale periods can lead to more favorable contracts, allowing to cut back on the marketing and sale costs. Overall, given the variability in harvesting and marketing costs, we exclude these costs from the analysis. The estimated return was calculated as the product of marketable yield and market price. The breakeven point was calculated as the minimum revenue generated by marketable yield required to offset the preharvest production costs.

A sensitivity analysis was performed to compare net returns and breakeven points of cabbage grown using the bare ground and plasticulture systems. Specifically, to capture the range of net returns possible for the northeast Florida cabbage production season, a range of marketable yields and sale prices was considered. Marketable yield estimates from the production trials were used (mean marketable yield $\pm$ 1.725 SE). The SE value was determined as confidence interval of 90% given 20 df. The range of Florida cabbage price per hundred-weight used in the sensitivity analysis was from the period of 2010 to 2014 (USDA, 2015).

Results and discussion

The costs of the minimum equipment required to convert seepage to a plasticulture system were estimated at \$651/acre (Table 1). Those materials, if well maintained, can have a minimum lifespan of 5 years; therefore, those expenses were depreciated, resulting in \$130/acre annual costs. It is important to note that the investment costs are highly farm specific, and depend on the configuration of the production field as well as the type of the irrigation water source. For instance, the distance between the cultivated field and water source, area to be irrigated, or drip tape requirements may result in different water pump requirements to provide enough water volume and pressure for proper operation. The water pump cost may be omitted for farms that are already equipped with sufficient pumps, which could result in reduction of the estimated capital cost of converting by 60%. The fertilizer injection pump can also vary according the size of the area being fertigated and the amount of solution to be injected in the irrigation line. Barrett et al. (2014) described a baseline

investment scenario for converting from seepage irrigation to a plasticulture system for vegetable production, providing information about well adaptation, water pump requirements, and drip irrigation maintenance.

Plasticulture preharvest costs were \$1691/acre (56%) higher than seepage (Table 2). The use of a higher plant population with plasticulture increased the cost of transplants by \$111/acre compared with seepage. Overall, transplant expenses represented 11% and 9% of the budget for the bare ground and plasticulture systems, respectively. Fertilizer expenses accounted for 22% of the total preharvest costs of seepage and plasticulture. Fertilizer represented the highest line-item cost of the budget for both production systems. Bare ground production with seepage irrigation has been characterized as having low irrigation efficiency and a high vulnerability for nitrate leaching (Munoz-Arboleda et al., 2008), which increases the risk of nutrient losses. A benefit of plastic mulch with irrigation and fertigation made via drip tape is the increased fertilizer use efficiency and reduction in losses from leaching (Romic et al., 2003). Bare ground production required the use of a tractor and labor at least twice during the growing season to make side-dress fertilizer applications and twice more to cultivate weeds. These practices can be eliminated by fertigation and through the exclusion of weeds through the use of plastic mulch. However, for the plasticulture system, bed preparation and laying plastic mulch and drip tape require tractor use and labor, and fertigation requires labor. In the two seasons of this study, labor and machinery costs for the plasticulture system were similar to that of the traditional bare ground system and because there is flexibility in production decision-making and variability in the year-to-year requirements for labor and machinery use, the labor and machinery costs for both systems were considered equivalent.

For the plasticulture system, the plastic mulch, drip tape, and irrigation fittings accounted for 21% of the total preharvest costs. The cost of plastic mulch was calculated as \$392/acre, which was \$117/acre more expensive than the costs with black plastic mulch reported by Bangarwa et al. (2010). This difference is mainly due to the wider plastic used to cover the 48-inch-wide raised bed reported here,

Table 1. Investment costs for converting seepage system into plasticulture system (converted to per-acre basis) for cabbage production.^z

Item	Unit	Price (\$/unit) ^y	Total (\$/acre)
Pump 50 gal/min (189.3 L·min ⁻¹)	1	400	400
Disk filters	2	50	100
Liquid fertilizer injection pump	1	130	130
Double control valve	1	10	10
Pressure regulator	1	11	11
Total			651
Cost/year ^x			130

^zThe cost of drip tape, plastic mulch, and polyethylene pipes are excluded from the investment costs, but accounted for in annual production budget.

^yBased on 2013 and 2014 prices.

^xStraight line depreciated with expected minimum lifespan of 5 years.

Table 2. Preharvest costs of cabbage produced under seepage irrigation system with 19,600 plants/acre and drip-irrigated plasticulture system with 26,136 plants/acre.^z

	Seepage (\$/acre) ^z	Plasticulture (\$/acre) ^z
Preharvest variable costs		
Cabbage transplants	332.98	444.01
Fertilizer	657.00	1,050.80
Fumigant	150.00	150.00
Herbicide	34.40	34.40
Insecticide	199.33	199.33
Plastic mulch	—	391.75
Drip tape	—	556.80
Irrigation fittings	—	55.68
Polyethylene pipes	—	64.00
Fungicide	33.00	33.00
General farm labor	245.01	245.01
Plastic mulch and drip installation	—	16.98
Tractors and equipment		
Machinery variable cost	270.13	270.13
Tractor driver labor	121.29	121.29
Miscellaneous		
Farm vehicle	18.21	18.21
Cover crop seed	20.00	20.00
Transplanting labor	170.00	226.10
Total operating cost	2,345.15	4,036.04
Fixed costs		
Land rent	150.00	150.00
Machinery (including depreciation)	62.30	192.50
Farm management and overhead	478.22	478.22
Total fixed cost	690.52	690.52
Total preharvest cost	3,036.67	4,726.56

^z1 plant/acre = 2.4711 plants/ha; \$1/acre = \$2.4711/ha; \$1/cwt = \$0.0220/kg.

compared with 36-inch-wide bed used for tomato and other vegetable crops. The wider bed used for cabbage production requires two drip tape lines instead of one, as is commonly used for other vegetable crops grown using plasticulture. This represented a higher cost for drip tape as compared with other plasticulture systems. The difference in bed size between cabbage and other vegetable crops requires either the acquisition of

new implements or the adaptation of implements already in use. The potential reuse of the plastic mulch and drip tape for a subsequent crop (Lamont, 1993; Orzolek, 1996) may aid in mitigating the cost of new equipment or modifications, although costs for the removal and disposal of the plastic after the growing season(s) was not included here.

A sensitivity analysis was performed to estimate the net return per

acre of cabbage grown under plasticulture and evaluate its feasibility throughout the cabbage growing season. Plasticulture showed a higher preharvest production cost than seepage; therefore, plasticulture is only economically feasible if the total expenses are offset by the increase in marketable yield.

The Florida bare ground average yield was 339 cwt/acre from 2005 to 2014, whereas the average price was \$18.0/cwt for the same time period (USDA, 2015). The mean bare ground net return from the past 10 years of data can be estimated at \$3066/acre when preharvest costs are accounted for. From 2005 to 2014 cabbage prices ranged from \$11.8 to \$24.1 per cwt (USDA, 2015). Given the lowest price observed (\$11.8/cwt), the breakeven point was estimated at 257 cwt/acre for the bare ground system.

Similar to other vegetable crops (Locascio, 2005), cabbage production using plastic mulch and drip irrigation also showed an increase in productivity (Barrett et al., 2015; Paranhos et al., 2016). The SEP planting date produced a highest mean marketable yield of 563 cwt/acre and at the lowest historical price per cwt (\$11.8/cwt), the estimated net return was \$1916/acre (Table 3). NOV planting also showed a higher mean marketable yield compared with the traditional seepage system (404 cwt/acre compared with 339 cwt/acre), even though the mean yield was lower than those observed for the other planting dates considered. The estimated net return given mean marketable yield and NOV planting was \$40 and \$2545 per acre at prices of \$11.8/cwt (lowest) and \$18.0/cwt (average), respectively. The marketable yields and net returns for the OCT and DEC plantings were between the values observed for the SEP and NOV plantings (Table 3).

For September and October planting, the annual returns are about equal or exceed the per-acre investments needed to convert seepage to plasticulture system (\$651/acre), implying that the producer can recover the investments needed for the system within 1 year (i.e., the payback period is less than or equal to 1 year). Similarly, for December planting, the payback period is equal or less than 1 year, except the case when the sale price and yield are low. However, even in the extreme case when the price is

Table 3. Average marketable yield and estimated net return per acre of cabbage planted in 4 different months under drip-irrigated plasticulture in northeast Florida in 2013–14 and 2014–15.

Mo. ^z	SE ^y	Yield (cwt/acre) ^{y,x}	Estimated net return (\$/acre) ^{x,w}							
			Price (\$/cwt) ^{x,v}							
			10	12	14	16	18	20	22	24
SEP	–1	547	743	1,837	2,931	4,025	5,119	6,213	7,307	8,401
	Mean	563	903	2,029	3,155	4,281	5,407	6,533	7,659	8,785
	1	578	1,053	2,209	3,365	4,521	5,677	6,833	7,989	9,145
OCT	–1	532	593	1,657	2,721	3,785	4,849	5,913	6,977	8,041
	Mean	548	753	1,849	2,945	4,041	5,137	6,233	7,329	8,425
	1	563	903	2,029	3,155	4,281	5,407	6,533	7,659	8,785
NOV	–1	388	–847	–71	705	1,481	2,257	3,033	3,809	4,585
	Mean	404	–687	121	929	1,737	2,545	3,353	4,161	4,969
	1	419	–537	301	1,139	1,977	2,815	3,653	4,491	5,329
DEC	–1	523	503	1,549	2,595	3,641	4,687	5,733	6,779	7,825
	Mean	538	653	1,729	2,805	3,881	4,957	6,033	7,109	8,185
	1	553	803	1,909	3,015	4,121	5,227	6,333	7,439	8,545

^z‘Bravo’ cabbage was transplanted on 17 Sept. (SEP), 11 Oct. (OCT), 7 Nov. (NOV), and 3 Dec. (DEC) of 2013; and 16 Sept., 9 Oct., 4 Nov., and 2 Dec. of 2014.

^yMarketable yield presented were the estimated mean yield for 2013–14 and 2014–15 season $\pm$ 1.725 SE of each planting date treatment.

^x1 cwt/acre = 112.0851 kg·ha^{–1}, \$1/acre = \$2.4711/ha, \$1/cwt = \$0.0220/kg.

^wMatrix values represent [(marketable yield $\times$ \$/cwt)–plasticulture preharvest costs]. Other production and harvest costs must be factored in to achieve a full net return per acre.

^vPrices were based on the market price per cwt in Florida from 2011 to 2014 (USDA, 2015).

\$10/cwt and the yield is 523 cwt/acre, the payback period is only 1.29 years. The longest payback period of 5.38 years is observed for November planting date when the price is \$12/cwt, and given the mean yield observed (404 cwt/acre). Note also that for the November planting, the producer would not be able to pay back the investment cost if the price is \$10/cwt, or if the price is \$12/cwt, and the yield is low (see the negative net returns in Table 3).

From 2005 to 2014, cabbage prices ranged from \$11.8 to \$24.1 per cwt (USDA, 2015), resulting in varying net returns. Overall, the breakeven point for the plasticulture preharvest production cost at a lowest historical price of \$11.8/cwt was at a marketable yield of 401 cwt/acre. However, when the cabbage price was at its highest selling price (\$24.1/cwt), the breakeven point would be reduced to 197 cwt/acre based on the partial budget presented. This shows the importance of accounting for the variability in market prices in addition to the variability in yields in net return estimations. For producers interested in converting from bare ground to a plasticulture system, a yield of 433 cwt/acre would maintain their net return of \$3066/acre at the 10-year average price of \$18/cwt. Only the NOV planting date produced a mean yield that would result in a net return below the estimated \$3066/acre expected for bare ground. However, when all

plasticulture planting date means are combined, similar to that reported for Florida bare ground, the mean yield becomes 513 cwt/acre. This suggests a \$1447/acre on average increase in net return.

Air temperature has been identified as one of the major environmental factors influencing cabbage productivity (Criddle et al., 1997; Hara and Sonoda, 1982). Paranhos et al. (2016) reported that marketable yield responded quadratically to increasing mean growing season air temperature (Fig. 1A). With plasticulture, marketable yield was maximized when average air temperature was 63.5 °F during growing season. A reduction in marketable yield was observed as average air temperature departed from 63.5 °F. Sixty-four years of weather data (1950–2014) were used to determine the variability of average air temperature during a cabbage growing season of 100 consecutive days (equivalent range of days from transplant to cabbage harvest) starting at 5 Sept. to 26 Dec. (Fig. 1B). Cabbage transplanted at the beginning of the planting season (September) was expected to grow at average air temperatures above the optimum of 63.5 °F. Considering the average air temperature and its corresponding standard deviation in Fig. 1B, the optimum planting date for cabbage in the northeast Florida ranges from 14 Sept. to 3 Nov. During this planting date range, there was a 57% probability

that the average air temperature of the growing season will be near the optimum 60–65 °F, which promotes cabbage marketable yield. With the decrease of average air temperature to below 59 °F, a lower cabbage yield was expected for planting dates between November and the beginning of December. Plasticulture cabbage marketable yield throughout the growing season (Fig. 1C) was estimated by solving the yield response curve equation (Fig. 1A) with expected average seasonal air temperatures (Fig. 1B). Higher marketable cabbage yield with moderate variability was estimated when transplanting occurred in September and October, while lower marketable yield and greater variability were seen with planting dates from November through early December (Fig. 1C). The wide range of average air temperatures observed between November and December showed the possibility of producing a marketable yield below the breakeven point, at the lowest observed price, \$11.8/cwt.

A comparison of net returns among planting dates indicated that plasticulture may be more risky for planting dates (14 Nov. to 12 Dec.) when there was a 72% probability of average air temperature below 59 °F, thus weather conditions are less favorable for cabbage growth (Table 3). The lower net returns observed for the planting dates of mid-November to mid-December suggest that marketable yield during this part of the

Fig. 1. (A) Relationship between cabbage yield grown on drip-irrigated plasticulture system and average air temperature of cabbage growing season (calculated as average daily air temperature between transplant day and harvest day, total of 100 d); (B) historical average daily air temperature of growing season (100 d from planting) between 1950 and 2014 of northeast Florida; (C) the expected marketable yield based on the historical average air temperatures and the relationship between yield response to air temperature, average breakeven point for bare-ground seepage, and drip-irrigated plasticulture systems considering the lowest selling price of \$11.8/cwt (\$0.26/kg); $(1.8 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$, cwt/acre = $112.0851 \text{ kg}\cdot\text{ha}^{-1}$, \$/acre = \$2.4711/ha, \$/cwt = \$0.0220/kg.

growing season may be less profitable for plasticulture cabbage producers when all costs are considered and when prices are low.

Conclusions

Feeding a growing population while protecting water resources is a top priority for agricultural producers and other stakeholder groups nationwide. To address this challenge, farmers are seeking the opportunities to increase irrigation efficiency and to conserve water, while staying economically viable. Based on existing literature, plasticulture production can lead to a significant reduction in water use per pound of final produce and reduction in nutrient runoff/leaching; however, no past studies examined the economic costs and returns for plasticulture compared with seepage systems for cabbage specifically. In this study, cabbage grown under drip-irrigated plasticulture showed higher marketable yield than bare ground on seepage, with revenues offsetting the increase in preharvest production costs. The sensitivity analysis revealed that with planting dates from September to December, plasticulture was economically feasible when preharvest costs were considered. However, plasticulture cabbage production showed greater variability and an increased potential for reduced yield when planted between 14 Nov. and 12 Dec., regardless of the production system adopted. Although some planting dates were less favorable than others, when the entire growing season was considered, plasticulture showed the potential to increase average net returns by \$1447/acre. Note that in this paper we focused on the preharvest cost only. While preharvest cost account for the majority of production costs, while the harvesting costs are outside the scope of the analysis, individual producers considering plasticulture should consider potential increase in harvesting and packing costs as a result of the increased planting density.

Plasticulture results in a more efficient use of irrigation water and nutrients, potentially protecting and improving water quality in the region and reducing per-acre water withdrawals. The benefits of reduced nitrogen loading can include enhanced water-based recreational and commercial fishing opportunities, higher waterfront property values,

reduced adverse human health impacts associated with algal blooms, reduced drinking water treatment costs, and reduced costs of mitigation measures (USEPA 2015). For example, Elrich et al. (2016) found that the total value of nature-based recreation in St. Johns River Basin, northeast Florida, is \$172 million dollars per year, and this value depends on the perceived quality of water at the recreational sites. Further, Walsh et al. (2011) and Bin et al. (2016) estimated changes in waterfront property values associated with changes in water quality indicators in Orange and Martin counties, FL. They showed that changes in nitrogen concentration, water clarity, tropic index, and other water quality indicators correspond to thousands of dollars increases in the property values in proximity to the water bodies, and hence, increases in the taxes collected by local communities. Finally, Kreye et al. (2016) found that a median Florida household is willing to pay \$14.45 to \$64.56 per year for the policies protecting water quality and groundwater recharge (depending on the type of policy instrument used). While the current study focuses on the economic costs and benefits of plasticulture, additional studies are needed to better quantify the environmental benefits associated with the system, particularly focusing on water use and nutrient runoff reductions on farm and regional scales. Such studies will allow for better communication of agricultural water conservation efforts to the Florida public.

For growers deciding to use plasticulture for cabbage production, a gradual conversion from bare ground to plasticulture, which allows time to master the system, is recommended. Although the plasticulture system is shown to be more profitable for agricultural producers, its implementation involves up-front capital costs and higher annual operating costs. Changing production system from bare ground seepage to plasticulture will also require growers invest their time into learning the system and changing their farm management approaches. Such investments may not be feasible for some producers, especially small-scale operations with limited capital and human resources. Existing literature shows that adoption of conservation practices is usually lower for smaller farms with lower income and capital

(Baumgart-Getz et al., 2012; Pannell et al., 2011). Hence, a governmental cost-share program can be established to provide a financial incentive to increase grower adoption of best management practices such as plasticulture for production of cabbage and other vegetables. Participation in extension training programs, networking within the agribusiness sector, and interactions with neighboring farms have also been shown to increase the rate of adoption of conservation practices (Baumgart-Getz et al., 2012; Pannell et al., 2011), and University of Florida Extension faculty have been developing and implementing extension programs (including demonstrations, field days, and networking lunches) to deliver the information about plasticulture to the vegetable producers throughout the state.

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