Corn Nutritional Properties and Yields with Surface Drip Irrigation in Topographically Variable Fields†

H. Zhu[1]; Y. Lan[2]; M.C. Lamb[3]; C. L. Butts[3]
[1]USDA-ARS, ATRU, Wooster, OH 44691, USA. Zhu.16@osu.edu
[2] USDA-ARS, APMRU, College Station, TX 77845, USA. ylan@sparc.usda.gov
[3] USDA-ARS, NPRL, Dawson, GA 39842, USA. MLamb@nprl.usda.gov, cbutts@nprl.usda.gov

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ABSTRACT

Development of a method to effectively irrigate row crops that requires less capital investment than current methods will improve the economic feasibility of irrigation. A surface drip irrigation system was installed and investigated to irrigate a corn field with very little topographic variation (Plot 1) and another field with undulating terrains containing 1.75% slopes (Plot 2). Drip tapes with lateral spacing of 0.91 m and 1.82 m were placed on the soil surface 3 cm away from a planting row and in the middle line of two planting rows, respectively. Corn grain yield and nutritional properties with surface drip irrigation treatment were compared with the corn produced in the adjacent non-irrigated zones. With surface drip irrigation, the average corn yield was 8,451 kg/ha in Plot 1 and was 10,920 kg/ha in Plot 2, while without irrigation the yield was 1461 kg/ha in Plot 1 and 450 kg/ha in Plot 2. There were no significant differences ($p<0.05$) for yields between 0.91 m and 1.82 m drip tape lateral spacings. No significant yield differences between low and high plant populations were observed in non-irrigation zones,. Compared to non-irrigation treatment, surface drip irrigation greatly reduced variations in corn yield and nutritional properties in undulating terrain field. Corn kernels with surface drip irrigation contained higher carbon to nitrogen (C/N) ratio and lower protein content, crude fiber, ash and fat or oil (F/O) than non-irrigation treatments. The inexpensive surface drip irrigation greatly increased corn grain yields and improved nutritional properties.

Keywords: Grain, trickle irrigation, water conservation

1. INTRODUCTION

Corn is one of the major row crops and is also a major peanut rotation crop in the Southeastern United States. It has imposed great economic impact on farmers. In 2001, there were about 202500 ha of corn planted for grain in Alabama, Florida and Georgia with a farm gate value of 104 million US dollars. The average Southeastern corn price was 8.46 US dollars per 100 kg compared to 14.17 US dollars per 100 kg in 1996 in which over 364200 ha were planted with a farm gate value of approximately 295 million US dollars. Reducing the production cost is a major issue for corn growers to maintain their profit.

As increases in competition with other water users coupled with increasing investment and operating cost for irrigation, many farmers are looking for alternative irrigation methods to maximize water use efficiency while maintaining profitable yield and acceptable quality. Drip irrigation could increase yield by 30% or more than sprinkler or furrow irrigation (Goldberg and

Shmueli, 1970), and offer the best method of supplying uniform soil moisture in the root zone throughout the growing season (Sammis, 1980).

Considerable research has been conducted to increase corn grain yield with different irrigation methods (Hook et al., 1984; Cassel et al., 1985; Gascho and Hook, 1991; Caldwell et al., 1994; Lamm et al., 2001; O'Brien et al., 2001; Camp and Sadler, 2002). Corn grain yields greatly increased with irrigation, but no significant differences between subsurface and surface drip irrigation were observed (Camp et al., 1989). Powell and Wright (1993) evaluated corn yields with three drip line spacings buried 0.38 m below the soil surface. No economic difference was found in corn between irrigation lines placed under alternate corn row middles and under each third row. Corn yields and protein content significantly increased as nitrogen application rates regardless of application methods (Feng and Smith, 1993; Singh et al., 2002).

Corn grain is a major high quality feed used in dairy and beef cattle farms in the USA due to its high energy and easy digestibility. The raw materials of feed require quality control of some basic nutritional properties such as protein content, C/N ratio, F/O content and crude fiber content that are essential for livestock feed formulation. Current concern has increased awareness of methods to reduce excessive nitrogen in livestock manure and use genetically modified corns to increase protein and energy content of corn. Little information is available on how irrigation can improve the corn nutritional properties.

Many research efforts have been aimed at improvement of corn yield, irrigation water efficiency and nutrient management efficiency in flat areas. However, very little research has been done on the use of surface drip irrigation to improve corn yield and nutritional properties under undulating topographic field conditions. Differently from subsurface drip irrigation which places drip tapes under the soil, surface drip irrigation simply places drip tapes on the soil surface with much lower initial investment and easier maintenance during the growing season. The overall objective of this research was to evaluate an inexpensive surface drip irrigation system in a field with varying elevations to produce high corn grain yield and improve corn nutritional quality. The specific objectives of this research were to compare corn grain yield and major nutritional properties including C/N ratio, % F/O, % crude fiber and % ash between surface drip irrigation and non-irrigation treatments, and to determine the effect of drip line spacing and topographic variation on corn yield and nutritional properties.

2. MATERIALS AND METHODS

2.1. Test Plot Selection

Two experimental plots in southwestern Georgia were selected to conduct tests. One plot (Plot 1) had very little topographic variation. Another plot (Plot 2) was an undulating terrain with 1.75% slopes. Plot 1 contained three separate zones for three replications (Fig. 1). Peanut and cotton were planted between zones as rotation crops (Zhu et al., 2004a). Each zone in Plot 1 was 60 m long and 20.1 m wide, consisting of 11 beds: three for border row, two for each of surface drip irrigation treatments with 0.91 m and 1.82 m lateral spacings, two for non-irrigation with low seed population, and two for non-irrigation with high seed population. Figure 1 gives details on the bed layout for each zone in Plot 1.

Plot 2 consisted of a surface drip irrigation zone and a non-irrigation zone (Fig. 1). Each zone was 0.25 ha with fourteen beds, 90 m long and 1.82 m wide. In the surface drip irrigated zone, four beds were used as border row, three beds used as 0.91 m lateral spacing treatment, and seven beds as 1.82 m lateral spacing treatment. The number of beds for each treatment represented the number of replications for that treatment. For non-irrigation treatment, there were 10 beds representing 10 replications. Elevation survey was conducted at 90 points evenly distributed in each zone. The survey for each zone was referenced at the beginning of the first border row (Fig. 1). The land elevation varied from 19 cm to 66 cm, or 35% coefficient of topographic variations (average elevation divided by standard deviation) in the non-irrigation zone, and from -22 cm to 58 cm, or 161% coefficient of topographic variations in the drip irrigation zone.

2.2. Drip Irrigation Design

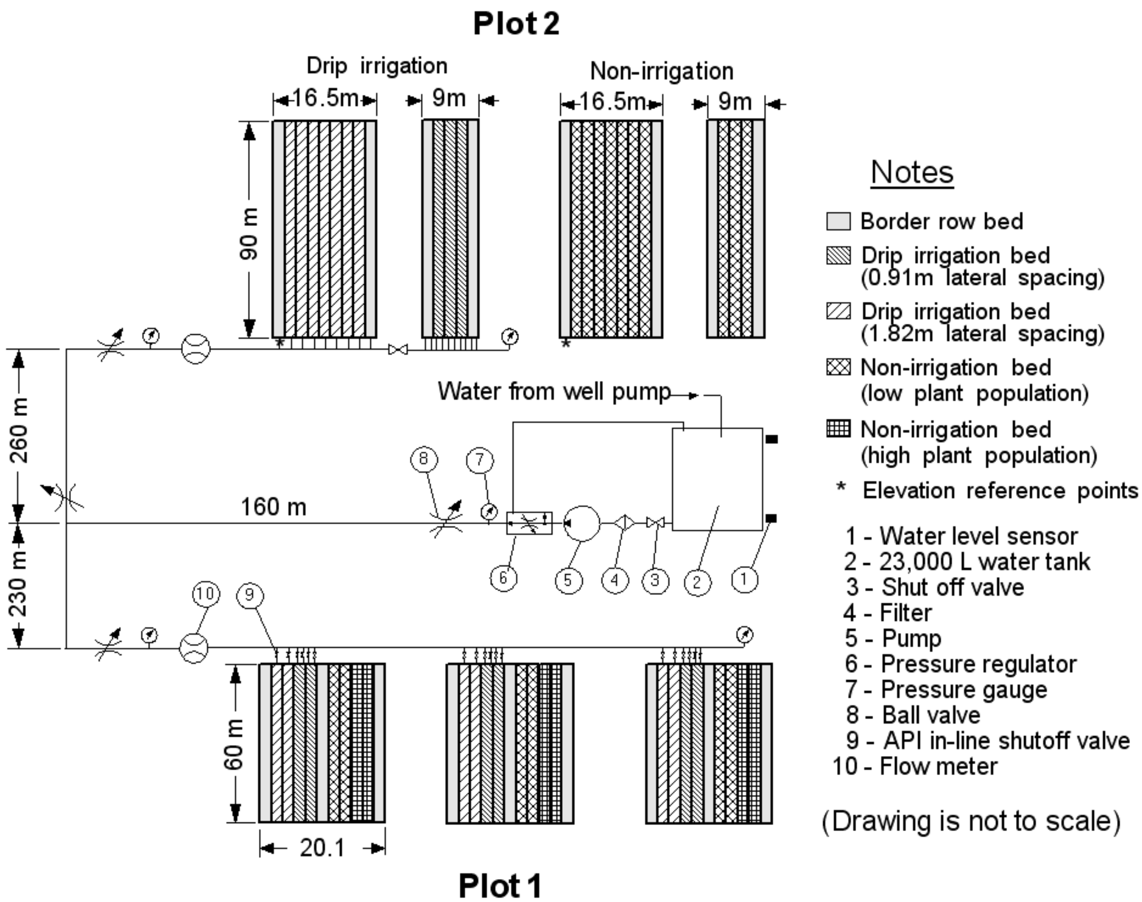

Figure 1. Experimental design with a surface drip irrigation system to grow field corn in Plot 1 with little topographic variation and Plot 2 with undulating terrains containing 1.75% slopes.

Drip tape with 0.200 mm wall thickness and 30 cm emitter spacing were installed on the soil surface in irrigation zones with 0.91 and 1.82 m lateral spacings in both Plot 1 and 2. For the 1.82 m lateral spacing, one drip tape was installed at the middle line between two rows on each bed. For 0.91 m lateral spacing, two drip tapes were installed on each bed and each tape was about 3 cm from each plant row. The flow rate from each emitter was 0.031 L/min operated at 55 kPa pressure. Drip tapes were installed with a surface drip irrigation tape installer/retriever (Zhu et al., 2004b). To block water flowing out at the end of tape, the tape end was folded twice and the folded section was sleeved with a 6-cm long piece of drip tape.

Flexible hoses, 5-cm in diameter, were used to deliver water to drip tapes. To connect drip tape to the delivery hose, an adapter containing a shutoff valve (Model 400-BV-06-LS, Agricultural Products, Inc., Ontario, CA) was used in Plot 1 while an adaptor without a shutoff valve (Model 400B-06-LS, Agricultural Products, Inc., Ontario, CA) was used in Plot 2. A modified 0.6-cm diameter Phillips screw driver with the sharpened end was used to punch holes in the delivery hose for installation of the adapters.

Ground water was delivered to a 23,000 L plastic tank, and then was applied to the field with a centrifugal pump from the tank (Fig. 1). Another well pump was used to refill the water tank, and it was controlled with two capacitive, normally closed water level sensors. A 3.2-cm pressure regulating valve and a ball valve were installed downstream the centrifugal pump discharge for adjusting pressure to 70 kPa. The regulating valve bypassed extra water back to the tank. Water flow to each plot was measured with a 5-cm T-10 water meter (Neptune Technology Group Inc., Tallassee, AL).

Corn was irrigated according to the schedule recommended by the Cooperative Extension Service of the University of Georgia, College of Agriculture (Smith, 1990). Total amount of water provided by drip irrigation to the corn on both 0.91 m and 1.82 m lateral spacing plots was 193 mm (Fig. 2). Irrigation amounts applied during each irrigation event was increased after corn tassels were developed. Total precipitation received during the growing season was 598 mm.

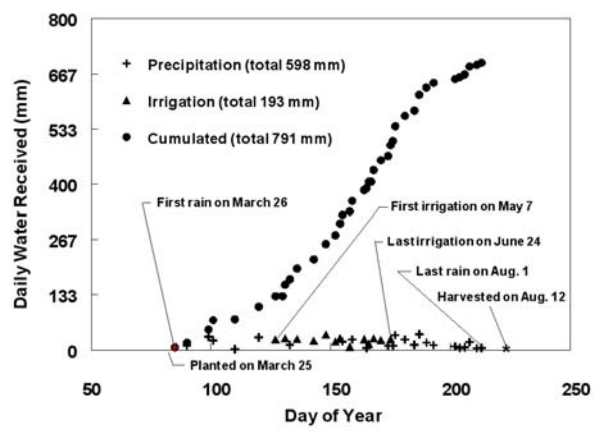

Figure 2. Precipitation and amount of surface drip irrigation applied to corn plants during the growing season.

2.3. Land Preparation and Chemical Application

The soil type in Plot 1 and Plot 2 was Greenville (fine, kaolinitic, thermic Rhodic Kandiudults) which was dark brown sandy loam from soil surface to 20 cm below the surface, and was dark red clay loam between 20 and 30 cm below the soil surface. Before the planting, the soil contained 31.4 kg/ha of phosphorus, 248 kg/ha of potassium, 1100 kg/ha of calcium, 260 kg/ha of magnesium, 1.03 kg/ha of zinc, and 17 kg/ha of manganese, and the soil pH was 5.9. Based on these values, 1120 kg/ha lime, 135 kg/ha nitrogen, 67 kg/ha phosphate, and 22 kg/ha potash were applied to the non-irrigated zones in Plot 1 and 2, 30 days before planting as recommended by Soil, Plant and Water Laboratory of the University of Georgia. In the irrigated zones, 1120 kg/ha limestone, 202 kg/ha nitrogen, 112 kg/ha phosphate, and 78 kg/ha potash were applied. In addition, elemental zinc at rate of 3.4 kg/ha was applied to both plots. The soil was then tilled with subsoiler and rototiller before planting.

Dekalb 687 corn was planted with a pneumatic planter near the end of March. The target plant population was 84,000 plants/ha (high plant population) in the irrigated zones, and 53,800 plants/ha (low plant population) in the non-irrigated zones, as recommended by Soil, Plant and Water Laboratory of the University of Georgia. For comparison, the non-irrigated zones in Plot 1 also contained six beds planted with high plant population. Spacing between two plant rows was 0.91 m. The herbicide, Sutan Plus, was applied before planting, and Atrazine with crop oil was applied 24 days after planting. The corn in each individual bed was harvested with John Deere 4420 combine in the middle of August when the moisture content reached 17% in irrigated zones and 15% in non-irrigated zone. The grain yields were adjusted to 15% moisture.

2.4. Nutritional Property Analysis

Corn kernel samples were randomly collected from each planting bed in drip irrigated zones containing two lateral spacings and non-irrigated zones containing low plant population in both Plot 1 and 2 during the process of harvesting. Each sample weighed 500 grams for nutritional property analysis.

A Vario MAX analyzer (Model CN) was used to determine C/N ratio and total protein content in the corn kernel. Percentage of protein (% protein) on dry matter was calculated from the measured nitrogen content. All samples were combusted at approximately 1000°C for direct analysis.

The percentage of F/O (%F/O) was determined with the Soxtec System HT 1043 extraction unit. Samples were ground to 1 mm particles by a knife mill. Ethyl ether was used to extract the F/O content.

The amount of crude fiber was quantitatively determined with an ANKOM^{200} Fiber Analyzer in conjunction with ANKOM's F57 filter bags and No. 1915 heat sealers. The % crude fiber based on dry matter and % ash were then calculated from the weight loss by heating to 550°C for a period of two hours.

2.5. Data Analysis

Test data were analyzed by one way ANOVA, and differences among means were determined with the Student-Newman-Keuls Test using Sigma Stat version 2.0. All significant differences were determined at 0.05 level of significance.

3. RESULTS AND DISCUSSION

3.1. Drip Irrigation System

The surface drip irrigation systems in both Plot 1 and 2 operated satisfactorily throughout the corn growing season. Drip tapes were retrieved before harvesting. The tapes with 0.91 m lateral spacing were lifted before retrieval because some tapes were covered by corn roots. Rodent damages to drip tapes were not found with this application. This evidence was probably because rodents were not active under the circumstances during the period of corn growing season and corn plants were too tall to create shade for rodents to hide. No serious problems were encountered during the drip tape installation or retrieval, nor due to emitter plugging and drip tape constriction.

3.2. Grain Yield

The corn grain yields in the surface drip irrigated zones were substantially higher than non-irrigated zones in both Plot 1 and 2. Statistical analysis indicated no significant differences in yields between 0.91 m and 1.82 m lateral spacings. For each 1-ha of land, it could save 5468 m drip tape, half number of fittings and installation time from using 1.82 m tape lateral spacing instead of 0.91 m lateral spacing. Therefore, using a 1.82 m lateral spacing could greatly reduce installation cost with no significant reduction in yield. Similarly, no significant differences for yields due to plant population in non-irrigation zones were observed. Under similar rainfall conditions, the lower seeding rate could be used in non-irrigated situations and not significantly affect yields, which would reduce production cost considerably.

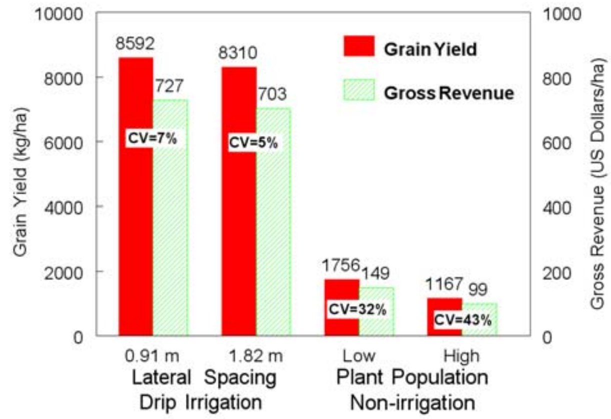

Figure 3. Comparison of corn yields and gross revenues between surface drip irrigation with two lateral spacings and non-irrigation with two plant populations in Plot 1. CV is the coefficient of variation of the average grain yield.

In Plot 1, the average yield with surface drip irrigation was 5.8 times higher than the non-irrigation (Fig. 3). The average grain yield in Plot 2 with drip irrigation was 10920 kg/ha while the non-irrigated plot produced only 450 kg/ha. Non-irrigated zones in Plot 2 produced less corn than Plot 1. This evidence was probably because the capability of soil retaining water in Plot 1 was greater than in Plot 2 due to differences in the land slope. The gross revenue per ha based on 2001 corn price, 8.46 US dollars per 100 kg, was not significantly different between lateral spacings in surface drip irrigation zones or plant populations in non-irrigation zones, but were significantly higher in the surface drip irrigation zones than the non-irrigation zones (Fig. 3).

Table 1. Comparison of corn grain yields from surface drip irrigated and non-irrigated zones in Plot 2 with different land elevations

Surface Drip Irrigation		Non-irrigation	
Land Elevation (cm)	Yield (kg/ha)	Land Elevation (cm)	Yield (kg/ha)
-15	11926	20	562
-10	11507	24	641
-4	11088	30	397
2	10912	32	418
6	10874	33	439
10	10775	34	415
18	11171	36	367
43	10484	49	447
49	10672	54	415
53	10825	55	405

The net yield gain from irrigation, which is defined as the ratio of net increase of irrigated yield from non-irrigated yield to the total amount of water applied through irrigation during the growing season, was 36.2 kg/ha-mm in Plot 1 and was 54.2 kg ha^{-1} mm^{-1} in Plot 2. Theoretically, applying 1 mm water in a 1-ha field requires 10,000 L of water.

Table 1 shows the influence of land elevation on yields in both drip irrigated and non-irrigated zones in Plot 1. A negative value for the elevation represents the average elevation of the planting beds was lower than the survey reference point. Data in Table 1 indicated the grain yield varied considerably with land elevation variation in the non-irrigation zone while surface drip irrigation greatly reduced yield variation due to the land elevation variation. The coefficient of variation (CV) for the yield with drip irrigation was 3.9% while the CV for the land elevation in this plot was 161%. However, in the non-irrigated plot, the CV for the yield was 18.8% while the CV for the land elevation was 35%. Similar results for the CV with irrigation and non-irrigation treatments were also obtained in Plot 1 (Fig. 3).

3.3. Nutritional Properties

Statistical analysis indicated that there were no significant differences for the C/N ratio, % protein, % F/O, % ash and % crude fiber content due to lateral spacings with surface drip irrigation in both Plot 1 and 2; however, there are significant differences for these properties between irrigation and non-irrigation treatments except for %ash in Plot 1.

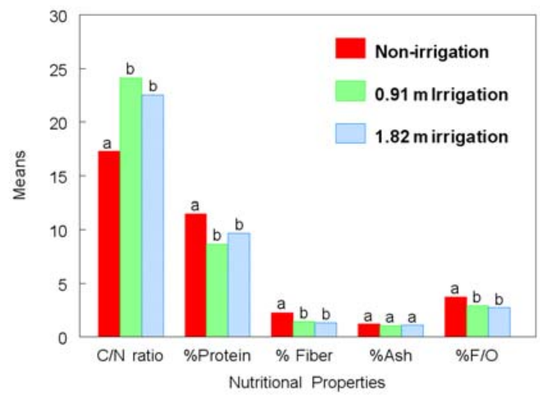

Figure 4. Comparison of corn nutritional properties between surface drip irrigation containing two lateral spacings and non-irrigation in Plot 1. Means with different lower case letters are significantly different, $p<0.05$.

Figure 4 compares the average values of C/N ratio, % protein, % F/O, % ash and % crude fiber for the corns from surface drip irrigation zones with two lateral spacings and a non-irrigation zone in Plot 1. The non-irrigated zones produced higher % protein content, % crude fiber, % ash and % F/O in corn kernels than surface drip irrigation zones. However, total amount of each protein content, crude fiber and ash and F/O in a hectare base from the surface drip irrigation zones was much higher than the non-irrigation zones because surface drip irrigation produced much higher corn yield. For example, the % protein from non-irrigated zones was 11.5, and was 8.7 for drip irrigated zones with 0.91 m lateral spacing, and was 9.7 for drip irrigated area with 1.82 m lateral spacing. However, the total amount of protein produced from corn grains in non irrigated zones was 202 kg/ha while the surface drip irrigated zones produced 747.5 kg/ha of protein with 0.91 m lateral spacing and 806 kg/ha of protein with 1.82 m lateral spacing.

The C/N ratio in corn kernels with surface drip irrigation in Plot 1 was significantly higher than non-irrigation (Fig. 4). Corn kernels from drip irrigated zones contained less nitrogen and higher carbon contents than non-irrigated zones. In this study, the average nitrogen content was 1.18% for the 0.91 m lateral spacing, 1.32% for the 1.82 m lateral spacing, and 1.57% for non-irrigation in Plot 1. Therefore, using surface drip irrigation increased carbon content and lowered nitrogen level in corn kernels. Ordinarily, farmers are cautioned about feeding corn with high nitrogen content due to potential toxicity.

Data in Figs. 5, 6, 7 and 8 illustrated that the C/N ratio, % F/O, % crude fiber and % ash from a corn kernel slightly increased as the land elevation increased for both irrigated zones with the elevation variation from -22 cm to 58 cm and non-irrigated zones from 19 cm to 66 cm. Similar to the result in flat area, drip irrigated corn kernels contained higher C/N ratio than the non-irrigated kernels (Fig. 5); however, % F/O, % crude fiber and % ash in the corn kernel from drip irrigated zones were lower than non-irrigated zones. The corn kernel in non-irrigated zones contained almost twice higher crude fiber than the corn kernel in the irrigated zones (Fig. 7).

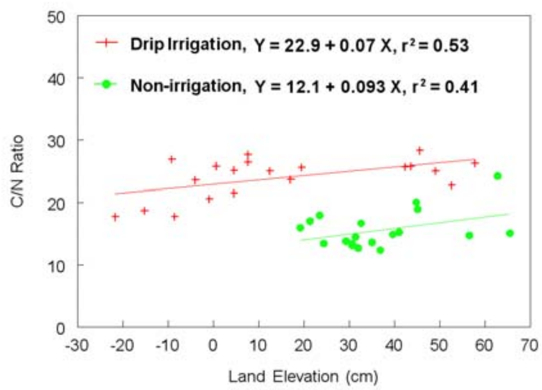

Figure 5. Effect of land elevation on C/N ratio of corn kernels from surface drip irrigated and non-irrigated zones in Plot 2.

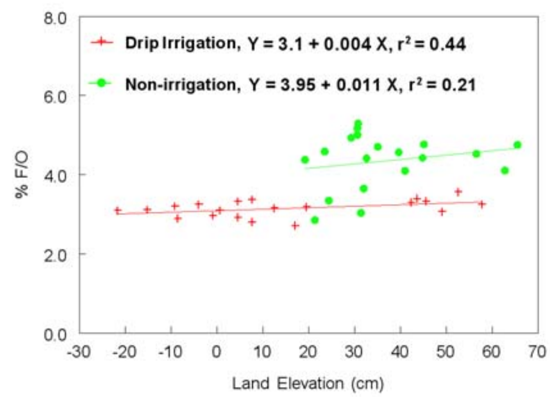

Figure 6. Effect of land elevation on % F/O of corn kernels from surface drip irrigated and non-irrigated zones in Plot 2.

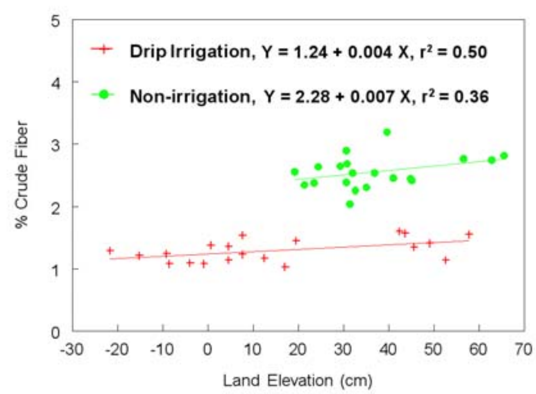

Figure 7. Effect of land elevation on % crude fiber of corn kernels from surface drip irrigated and non-irrigated zones in Plot 2.

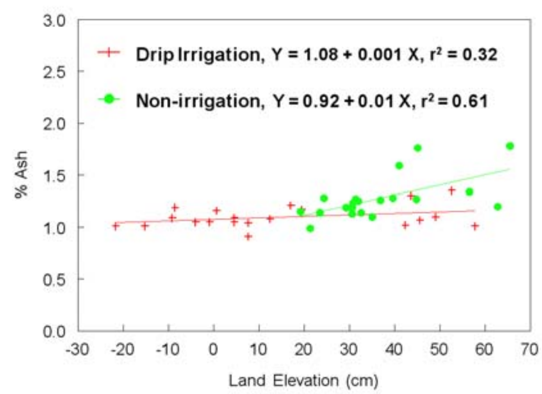

Figure 8. Effect of land elevation on % ash of corn kernels from surface drip irrigated and non-irrigated zones in Plot 2.

Steeper slopes of linear regression for the C/N ratio, % F/O, % crude fiber and % ash of corn kernels with the land elevation were found in non-irrigation zones than the irrigated zones. The slope of linear regression between the % ash and land elevation from the non-irrigated zones was about 10 times higher than the drip irrigated zones. Therefore, the land elevation had greater influence on nutritional properties of corn kernels from non-irrigated zones than drip irrigated zones.

Figure 9 shows that the % protein content in a single corn kernel slightly decreased as land elevation increased for both irrigated and non-irrigated zones. Corn at lower elevation produced higher protein content than that at higher elevation. Similar to the result in flat area, the protein content in kernels in irrigated zones in Plot 2 was lower than that in the non-irrigated zones.

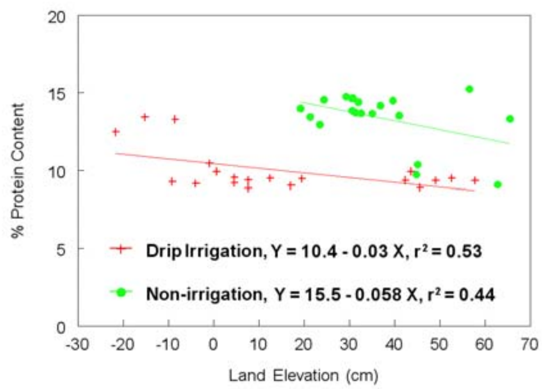

Figure 9. Effect of land elevation on % protein content of corn kernels from surface drip irrigated and non-irrigated zones in Plot 2.

4. CONCLUSIONS

Based on tests with surface drip irrigation to grow field corn in all fields with varied elevations, the following conclusions are highlighted.

- Corn grain yields from surface drip irrigation zones were substantially higher than non-irrigated zones in level and undulating plots. Statistical analysis indicated no significant differences in yields due to lateral spacings with surface drip irrigation. For non-irrigation treatment, there was no significant difference in grain yields between low and high plant populations.
- Surface drip irrigation produced corn with a higher C/N ratio and lower % protein content, % crude fiber, % ash and % F/O in corn kernels than non-irrigation.
- C/N ratio, % F/O, % crude fiber and % ash increased while % protein content decreased as the land elevation increased for both irrigated and non-irrigated areas. However, surface drip irrigation had lower changes in nutritional properties than non-irrigation.
- Surface drip irrigation greatly reduced corn grain yield variation because of the elevation variation. The net yield gain from irrigation was 36.2 kg ha^{-1} mm^{-1} in Plot 1 and was 54.2 kg ha^{-1} mm^{-1} in Plot 2.

5. ACKNOWLEDGEMENTS

The authors acknowledge Ernest M. Yoder and Jesse W. Childre for conducting field tests, and Shirley Wang for analyzing corn nutritional properties.

6. REFERENCES

Caldwell, D. S., W. E. Spurgeon and H. L. Manges. 1994. Frequency of irrigation for subsurface drip-irrigation corn. *Transactions of the ASAE* 37(4): 1099-1103

Camp, C. R. And E. J. Sadler. 2002. Irrigation, deep tillage, and nitrogen management for a corn-soybean rotation. *Transactions of the ASAE* 45(3): 601-608

Camp, C. R., E. J. Sadler and W. J. Busscher. 1989. Subsurface and alternate-middle micro irrigation for the southeastern coastal plain. *Transactions of the ASAE* 32(2): 451-456

Cassel, D. K., C. K. Martin and J. R. Lambert. 1985. Corn irrigation in humid regions on sandy soils with tillage pans. *Agronomy Journal* 77(6): 851-855

Feng, Z. and D. L. Smith. 1993. Corn yield and shifts among corn quality constituents following application of different nitrogen fertilizer sources at several times during corn development. *Journal of Plant Nutrition* 16(7): 1317-1337

Gascho, G. J., and J. E. Hook. 1991. Development of a fertigation program for sprinkler-irrigated corn. *Journal of Production Agriculture* 4(3): 306-312

Goldberg, D. and M. Shmueli. 1970. Drip irrigation - a method used under arid and desert conditions of high water and soil salinity. *Transactions of the ASAE* 13(1): 38-41

Hook, J. E. and L. Threadgill. 1984. Corn irrigation scheduled by tensiometer and the Lambert model in the humid Southeast. *Agronomy Journal* 76(4): 695-700

Lamm, F. R., T. P. Trooien, H. L. Manges and H. D. Sunderman. 2001. Nitrogen fertilization for subsurface drip-irrigated corn. *Transactions of the ASAE* 44(3): 533-542

O'Brien, D. M., F. R. Lamm, L. R. Stone and D. H. Rogers. 2001. Corn yields and profitability for low-capacity irrigation systems. *Applied Engineering in Agriculture* 17(3): 315-321

Powell, N. L. and F. S. Wright. 1985. Grain yield of subsurface microirrigated corn as affected by irrigation line spacing. *Agronomy Journal* 85(6): 1164-1169

Sammis, T. W. 1980. Comparison of sprinkler, trickle, subsurface, and furrow irrigation methods for row crops. *Agronomy Journal* 72(5): 701-704

Singh, M., M. R. Paulsen, L. Tian and H. Yao. 2002. Sie-specific study of corn protein, oil, and extractable starch variability using NIT spectroscopy. ASAE Paper No. 021111ASAE, St. Joseph, MI 49085

Smith, R. L. 1990. Growing Corn in Georgia. Cooperative Extension Service/University of Georgia, College of Agriculture, Bulletin 547

Zhu, H., M. C. Lamb, C. L. Butts and P. D. Blankenship. 2004a. Improving peanut yield and grade with surface drip irrigation in undulating fields. *Transactions of the ASAE* 47(1): 99-106.

Zhu, H., C. L. Butts, M. C. Lamb and P. D. Blankenship. 2004b. An implement to install and retrieve surface drip irrigation laterals. *Applied Engineering in Agriculture* 20(1): 17-23.