Use of Gravity Drip on the Navajo Nation

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ABSTRACT

Water supply and conveyance on the Navajo Nation is limited and many people are required to haul water for daily use from collection points. There are also large areas where electricity is not available. Simple drip irrigation systems offer an efficient water use solution for the cultivation of limited amounts of crops in rural areas without the need for a mainline water or electrical power supply. In this research, a two-year study was initiated in 2005 at the Hubbell Trading Post, a National Park Historic Site, located in Ganado, Arizona on the Navajo Nation. Drums filled with water supplied from a newly installed irrigation pipeline were used to feed low-pressure drip tape by gravity flow, in order to cultivate native corn. Gravity-fed drip irrigation systems were also set up in Tucson, AZ and Maricopa, AZ. Results from the Tucson and Maricopa sites showed that the systems could reliably provide irrigation water. By comparing three gravity-fed drip systems with a conventional surface irrigated plot at the Ganado, AZ site, yields of 3,675 kilograms per hectare (kg/ha) (average) and 4,011 kg/ha of dry grain were obtained with 663 mm (average) and 991 mm of water respectively in 2005. In 2005, surface water applied could only be estimated due to staff inexperience with the newly installed supply system. In 2006, using improved measurement techniques for the surface plot, yields of 3434 kg/ha (average) and 3301 kg/ha of dry grain were obtained with 704 mm (average) and 533 mm of water respectively for the drip and surface systems. Overall test results showed that acceptable corn yields could be achieved using inexpensive irrigation systems, very little labor, and a modest daily supply of water. Furthermore, results showed that the drip irrigation systems performed equally well compared to the surface plot.

BACKGROUND

The Hubbell Trading Post National Historic Site is located near Ganado on the Navajo Nation in Northeast Arizona. It is the oldest, continuously operated trading post on the Navajo Nation. The trading post was purchased by John Lorenzo Hubbell in 1878 and remained in the family until it was sold to the National Park Service (NPS) in 1967. The Trading Post site is located on 160 acres, one mile west of the small town of Ganado. In addition to the Trading post, there is a Visitor Center and the Hubbell home, all open to the public. The Trading post and historic site has become a key location within the Western Navajo Nation for both tourist and Navajo's alike.

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The irrigation system within the city of Ganado has recently been repaired and improved through the Ganado Irrigation and Water Conservation Project (GICP). The GICP was initiated and funded by several sources in the Federal Government and the Navajo Nation. Groups involved in a Memorandum of Understanding to collaborate in the development of agriculture in the Ganado valley included the Ganado Water Users Association, the Navajo Nation Department of Water Resources, the Navajo Nation Department of Agriculture, the Bureau of Indian Affairs (BIA), the Bureau of Reclamation (BOR), the Natural Resource Conservation Service (NRCS) and the National Park Service (NPS). Working through contracts with the BIA and Navajo Nation Department of Water Resources, the BOR began reconstruction and repair of the Ganado system. A total of $1.5 million was spent to upgrade the Ganado dam and the irrigation water delivery system. The goal is to re-establish agriculture in the Ganado area to a profitable enterprise.

METHODOLOGY

Experimental Site

The demonstration was conducted in 2005 and 2006 for a two-year period. Three sites were used to conduct the study. The irrigation systems used at all sites employed materials supplied by Chapin Watermatics, Inc. and Chapin Living Waters Foundation's Super Bucket Kit (Chapin Living Waters Foundation, 2007)[†].

Hubbell Trading Post Site

The main research site was located at the Hubbell Trading Post National Historic Site, located near Ganado, Arizona, on the Navajo Nation. The National Historic Site has a total area of 65 hectares and an elevation of 1932 m. The geographical location is at latitude 35° 42' 31" N and longitude 109° 33' 14" W. Two sets of soil samples from six depth increments (0-0.15, 0.15-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.9, 0.9-1.2 m) were obtained by soil auger. The soil texture was classified using the Bouyoucos Method and Calgon Hydrometer (Bouyoucos, 1936), which determined the percentage of sand (2.0 to 0.050 mm), silt (0.050 to 0.002 mm) and clay (<0.002 mm) in each soil sample. The soil samples were first dispersed to separate aggregates into individual granules. The different particle size fractions were then determined by sedimentation. Sand sized particles settled out within 40 seconds, clay sized particles settled out within two hours, and after two hours only the silt fraction remained in suspension. For additional details see Bouyoucos (1936). The electroconductivity (EC) of the soil samples was measured by electrode. De-ionized water was added to a weighed amount of each soil sample. These were placed on a stirring rack at high speed for one hour, and then centrifuged for half an hour. The supernatant was decanted and the EC was measured in μS/cm using an Accumet EC cell 13-620-155 containing two coiled

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[†] *Any products, services, or organizations that are mentioned, shown, or indirectly implied in this publication do not imply endorsement by The University of Arizona.*

contacts wrapped around a glass case separated by 1 cm. The conductivity was displayed on the Accumet Model 50 pH/Ion/Conductivity Meter. The EC of the irrigation water was measured using the same probe.

The layout of the National Historic Site and location of the research plots are indicated in Figure 1. The letter A shows the location of the Hubbell Trading Post buildings and the letter B shows the location of the agricultural field. Three replications of the drip-irrigated plots were used, each with dimensions of 6 m long and 4.5 m wide. The 6-meter long rows were oriented in a north-south direction and five lines of drip tape were laid out with a row spacing of 0.9 m, as shown in figure 2. The supply drum was located at the south end of the plot and was elevated 1.2 m above the ground. This layout was typical of all drip irrigation plots and research sites. The adjacent surface irrigated plot for comparison was laid out in an east west orientation with dimensions of 15 m long and 6 m wide. Figure 3 shows the layout of the three drip irrigated

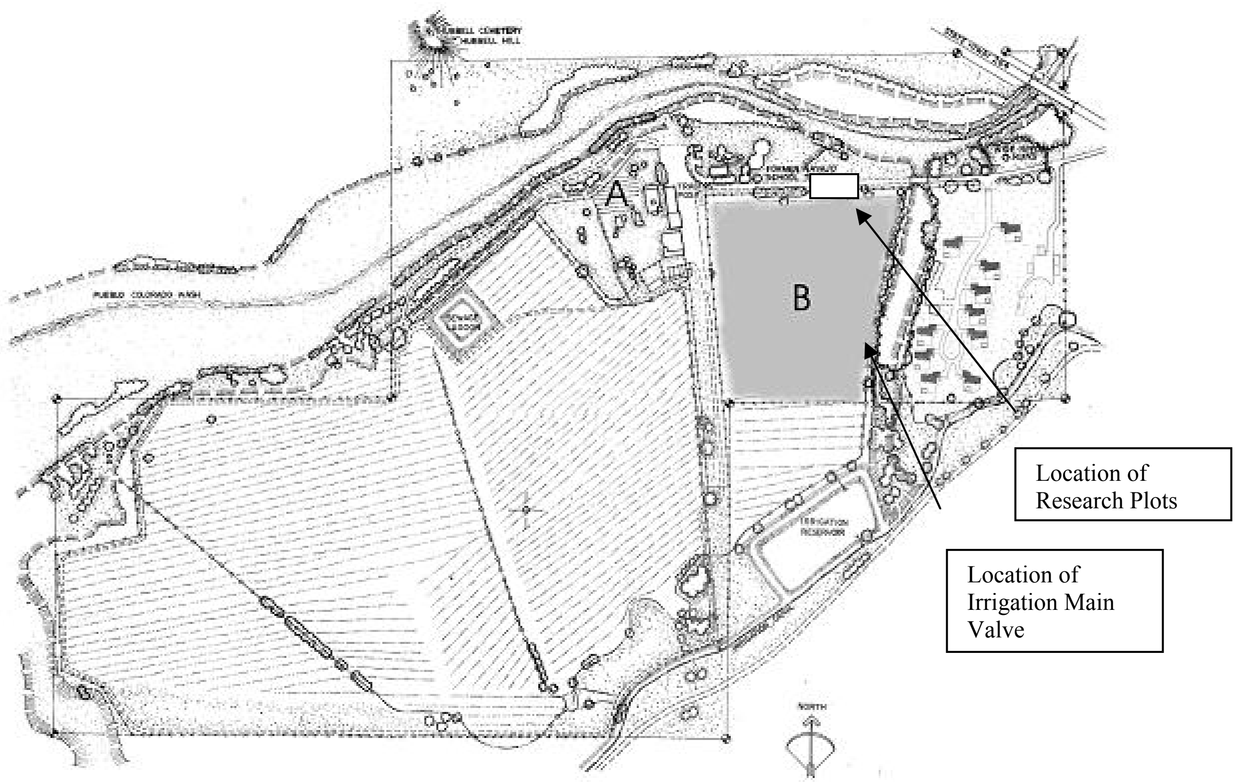


Figure 1. Layout of the Hubbell Trading Post National Historic Site with location of Hubbell Trading Post (A), Agricultural field (B) and location of research plots and irrigation main valve.

plots relative to the adjacent surface irrigated plot. In the first year, the surface plot was irrigated using a new gated pipe irrigation system installed by the Hubbell Trading Post. The surface plot was oriented to allow for direct irrigation from this system. Due to difficulties in measuring and controlling the water from the new irrigation system in 2005, a series of pipes and valves were connected downstream of a water meter in 2006 which allowed workers to irrigate parts of the plot as needed, and provided an accurate means of measuring water use.

Navajo White corn was planted on June 14th in 2005 and Navajo Yellow corn was planted on May 23rd in 2006. In both years, forage crops were grown on adjacent plots within the agricultural field on the Hubbell Trading Post property, which were grazed by sheep.

The field had not been cultivated for many years. The entire field was plowed, leveled and terraced prior to the 2005 season. Fertilizer in the form of horse manure was applied during the field preparation period. One east-west terrace was used to accommodate the three drip irrigated plots as well as the surface irrigated plot. Berms were constructed to prevent any water migrating from the other terraces onto the research plots. The irrigation water source was the Ganado reservoir, supplied to the Hubbell Trading Post site by the Ganado irrigation pipeline and Hubbell Trading Post irrigation lateral.

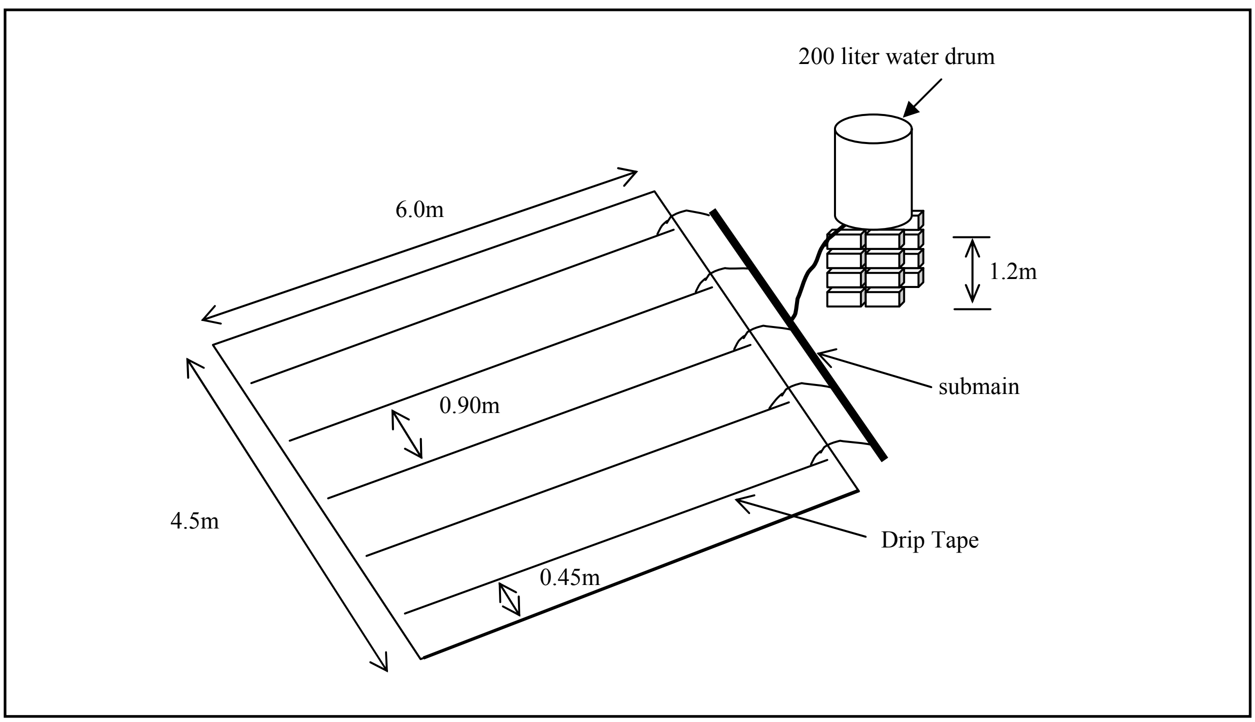


Figure 2: Layout of drip irrigation plots, typical for all plots and research sites.

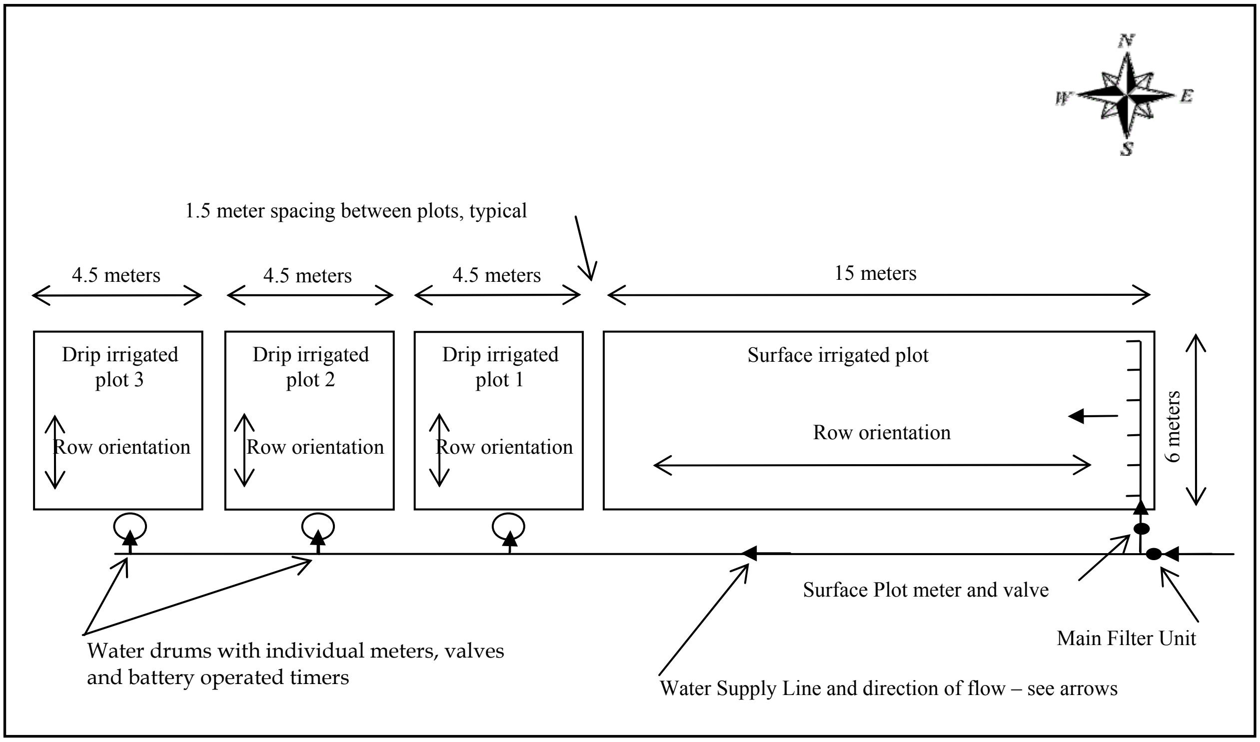


Figure 3: Layout of the drip irrigation plots relative to the surface irrigated plot, with row orientation. The surface plot water meter and valves were added in 2006. In 2005, the surface plot was irrigated by gated pipe, which ran along the eastern edge of the surface plot.

Water for the drip irrigation plots was taken from a connection point on the supply line located on the south-east corner of the agricultural field, immediately upstream of the main irrigation valve (Fig. 1) and was conveyed to the plots through approximately 275 m of 2.54 cm Schedule 40 Polyvinyl Chloride (PVC) pipe constructed for this project. Rainfall data were taken from the Ganado cooperative weather station data (NOAA, 2006). No rain monitoring equipment was set up at the site due to the periodic nature of field visits. Harvest dates were October 1st, 2005 and September 10th, 2006.

Equipment

All three of the drum irrigation systems were constructed of identical materials, with identical controls. Instrumentation was necessary in order to control daily watering intervals, avoid overflows, and monitor water use throughout the season.

Irrigation Drum

Recycled plastic drums were purchased from Sun West Container Company in Tucson, Arizona, a supplier of new and recycled drums. These drums were chosen on the basis of low cost, appropriate size for a daily watering volume, and durability to withstand transportation and handling stresses, as well as extreme heat and intense solar radiation experienced in Arizona.

The drums had previously been used for transporting food industry concentrates, and were equipped with two screw-in tops which had a molded 19 mm threaded outlet able to accept SCH 40 PVC fittings which made for easy attachment of valves as well as a leak-proof seal. The drums were used base-up in order to utilize these threaded connections as gravity fed outlets on the underside. A double outlet manifold was constructed from PVC fittings and was closed with two 13 mm PVC valves. A hole was cut in the base of the drum for access and an aluminum bracket was fabricated to hold a standard toilet cistern float valve assembly. The float valve was used as a failsafe check valve to prevent the drum overflowing in the event of timer failure. The aluminum bracket and float valve were bolted to the underside of the drum base adjacent to the access hole, and was adjusted using U-bolts for optimum float height.

Standard hoses and fittings were used to connect the stem of the float valve to a canister type filter unit and an automatic battery operated irrigation timer on the water inlet line which were fastened securely to the outside surface of the drum using U-bolts. The access hole was covered with a heavy rubber flap bolted in place on one side to allow flap access, and was designed to exclude insects, dust and other wind-borne debris. The drum was elevated to a height of 1.2m above the ground by fixing it on top of three columns of concrete blocks (each block sized 0.2 x 0.2 x 0.4 m), piled six high. The blocks were wired together for stability and the drums were held on top of the blocks with rubber ties stretched over the top of the drums. A view of the assembled drum is shown in figure 4, and the drums are shown in the installed position at the Hubbell Trading Post in figure 5. Figures 6 and 7 show the bracket holding the overflow prevention valve inside the drum, and the operation of the float valve respectively. Figure 8 shows the outlet valves which were used to connect the drum to the drip tape header using 8 mm tubing via slip-on connections.

Figure 4: View of the assembled irrigation drum.

Figure 5: View of the drums as installed at the Hubbell Trading Post research site.

Figure 6: Inside view of the irrigation drum showing the bracket holding the overflow prevention valve.

Figure 7: Overflow prevention valve operation: left picture shows float up (off) position, right picture shows float down (on) position.

Figure 8: Base of the irrigation drum showing PVC outlet valves and connections.

Irrigation Controller

A battery operated irrigation controller, inline spigot mounted type 62015 from Orbit, was used to control irrigation water applications (Fig. 9). The controls could be set to allow watering intervals of 2, 5, 10, 15, 30, 60, 90 and 120 minutes at set intervals between irrigation events of 2, 4, 8, or 12 hours, or daily, every second, third or fourth day, or once weekly. Initial tests showed that a drum would fill in less than 15 minutes at typical city water supply pressure and in approximately 25 minutes at pressure on the irrigation pipeline at the Hubbell Trading post. Being limited to the set times on the device a fill interval of 30 minutes was used (greater than the fill time of the drum), and the float valve was used to prevent overflow. At the end of the 30-minute interval the timer closed the main valve mechanically. As the outlet valves to the drip tubing were typically left in the open position, irrigation would begin as soon as the drum started to fill and the plots typically received more than a full drum of water on each irrigation event, being fed from the start of filling until the drums emptied.

Figure 9: Spigot Mounted Inline Irrigation Water Controller, model 62015 by Orbit.

Water Meter

In order to measure daily water use and cumulative water use for the season DLJ Hose Bibb Water Meters were installed on each system (Fig. 10). The water meters are accurate to standards specified by the American Water Works Association (AWWA). The water meters contain course mesh filters to exclude large debris from the unit and had to be checked at intervals. Standard 13 mm threaded male and female connections on the water meters allowed easy connection to hose fittings and automatic irrigation timers.

Figure 10: DLJ Hose Bibb (Sill Cock) Water Meter with 13 mm Garden Hose Thread inlet and Outlet.

Inline Filter

In 2005 small inline canister type filter units with removable screen filter tubes were used on each system (Fig. 11). In 2006 a much larger screen filter unit was used in the supply line upstream of all three systems at the Hubbell Trading Post (Fig. 12). This was done to reduce filter cleaning to one filter instead of three and provide a larger filter mesh area.

Figure 11: Thirteen mm MIPT 'Y' Irrigation Filter with threaded Cap.

Figure 12: Aquarius Brands Incorporated 5.1 cm T-type screen filter with bottom outlet for quick flushing.

Drip Tape

The Chapin drip tape used is sold as a kit specifically for use on small plots and is part of the Super Bucket Kit (Chapin Living Water Foundation, 2007). The drip tape is constructed from durable 15 mil plastic and is sold as a 90-meter roll of flat tape with precision laser-cut emitter slits every 30 cm. Inside the twin walled drip tape is a strip containing 10,000 filters per 30-meter length, which keeps water flowing in a turbulent flow regime and provides a self-cleaning function. The zig-zag pattern of this filter mechanism also helps to maintain a uniform pressure throughout the drip tape length (Fig. 13).

Figure 13: Section of Chapin Drip tape showing a slit emitter and the zig-zag pattern of filter within the twin-walled drip tape. Source: Chapin Watermatics Inc., 2007.

The kit includes 8 mm tubing for making the connection between the drum and the header tubing, as well as smaller diameter 5 mm tubing, which connects the header tubing to the drip tape. A larger 40 mm diameter section of tubing is used as a header for connecting a number of rows of drip tape to the irrigation source. All connections are made by inserting the small diameter tubing into holes in the drip tape and header tubing made with a sharpened nail of appropriate size (Fig. 14) which forms a watertight seal without the need for special fittings or connections.

Figure 14: Holes for inserting tubing are made by inserting a nail at 45 degrees through one side of the tubing and twisting. Source: Chapin Watermatics Inc., 2007.

The ends of the drip tape and header tubing are terminated by folding the tubing over itself and inserting the folded end into a short sleeve piece of the same tubing (Fig. 15).

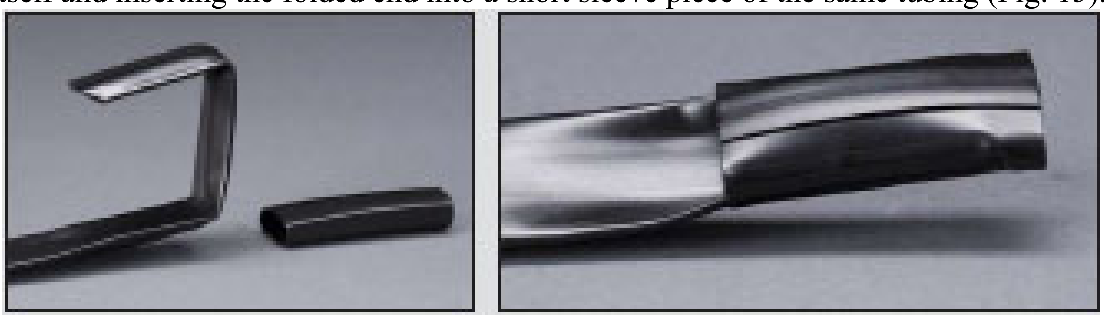


Figure 15: Ends of drip tape are terminated by folding the drip tape twice and inserting into a sleeve made of a short piece of the same drip tape. Source: Chapin Watermatics Inc, 2007.

These connections were found to be watertight and reliable. The drip tape was installed on the top of the ground with the emitters upward which help to prevent clogging by reducing the risk of suspended material in the water settling out and clogging the emitters.

Field Work

Installation of Supply Line

The 2.54 cm PVC supply line for the Hubbell research plots was laid along the historical surface irrigation ditch, which ran due north on the eastern side of the property. This amounted to approximately 275 m of piping. Individual control valves were installed for each system, and a main shut-off valve was installed at the tie-in point to the Hubbell Trading Post irrigation main valve at the south-east corner of the field (Fig. 1).

System Set-up and planting

The plots were leveled and measured out. Drip tape was cut and terminated, aligned north/south and connections were made to the submain. The drums were elevated (1.2m) on blocks and securely fastened. Meters, filters and automatic timers were connected together and tied into the supply line. Connections were made between the drum valves and the submain and all connections were tested for leaks. In 2005 the surface plots were irrigated using the newly installed gated pipe system. Unfortunately, problems with flow measurements made it difficult to determine accurately the amount of water applied to the surface plots. In 2006, the surface irrigation system for the surface plot was replaced with a furrow planting configuration with individual control valves at the head of each furrow as shown in Figure 16.

Planting in the drip irrigated plots was done by placing two seeds every 15 cm along the drip tape at a depth of 2.5 cm. Seeds were planted adjacent to each emitter and halfway between each emitter. Planting in the surface irrigated plot was done according to traditional Navajo methods of placing about 5-10 seeds in holes at intervals of approximately 0.6 m along the row. This traditional method of clumping the seeds together is thought to provide redundancy in case of plant death in the early stages, as well as protection for individual plants and less competition for soil moisture due to the greater spacing than used in conventional irrigated agriculture. Six rows of corn were planted in this way.

In 2005 and 2006, the drip irrigation systems were set up to water daily for 30 minutes each morning in order to provide 0.71 cm of water (maximum daily irrigation requirement at peak season) calculated for the entire plot area. This irrigation scheduling was increased in mid season by applying two drums of water per day (approximately 1.4 cm per day) due to plant requirements. In 2006, in an attempt to make more efficient use of water, a stepped approach to irrigation was used. One drum of water was applied daily in the initial growth period and two drums were applied daily from mid season until harvest. In both seasons, the surface irrigated plot was controlled by the agricultural crew at the Hubbell Trading Post and water was applied as needed.

The drums were washed out between the two growing seasons, and new drip tape was used in the second season. For research purposes it was thought best to use new drip tape in each season in order to more accurately compare results.

System Maintenance and Checking

System maintenance and data verification was done at approximately two-week intervals during the growing season. System maintenance included: observation of system operation, cleaning of filters, checking drip tape for leaks or blockages, timer maintenance, verification of data sheets, checking plant growth and monitoring for pests and disease, and discussion of any problems encountered by the Hubbell Trading

Post staff. The decision to increase the amount of water applied to the plots was based on field observations of plant conditions and soil moisture content.

Figure 16: Individual control valves at the head of each furrow, Hubbell surface plot, 2006.

Harvesting

Entire plants were harvested for analysis of dry plant biomass and dry kernel weight produced. Three separate samples of two-meter row length each were harvested from the surface irrigated plot according to a random sampling procedure which dictated the starting point for sampling. The outer rows were not sampled in order to avoid edge effect and samples were not taken from the first or last meter in any row for the same reason.

The drip irrigated plots were sampled in a similar way with the outer rows being excluded. A random row number was generated from the inner three rows and plants were harvested from a two-meter length in the center of the randomly chosen row. Once again this was done to avoid edge effect from the ends of the rows as well as from the two outside rows.

The full wet weight of plants (leaves and stalks) was measured, as well the weight of ears produced within the sample. The plant matter was sub-sampled and dried in ovens at 65 degrees Celsius. The ratio of wet to dry weight of the sub-sample allowed calculation of total dry biomass produced from each two-meter sample. The total number of ears in each sample were dried and shucked and the resulting kernels were weighed after being removed from the cob. A calculation was made for grain produced per m^2 and subsequent extrapolation for grain produced per hectare. As row spacing was 0.9 m, a two-meter long row sample was calculated as using 1.8 m^2 of field surface. The grain weight produced from each sample was converted to a kg/ha yield for general comparison.

Data Collection

The staff of the Hubbell Trading Post used bi-weekly record sheets to monitor daily water applied for the three drip irrigation systems and the surface irrigated plot by taking readings directly from the water meters. These data sheets were normally faxed once a week for checking in Tucson. The flow trends allowed monitoring of the daily operation of each system and frequency of irrigation events on the surface plot. This method of data collection was used to ensure daily monitoring of the systems for leaks or other damage, as well as for monitoring of effective operation of the irrigation controllers. Data was checked and verified at approximately two-week intervals by site visits throughout the growing seasons.

RESULTS AND DISCUSSION

Collection of data was done manually by regular visits to each site and by tabulating the water meter readings. The corn was sampled prior to general harvesting at the end of each growing season and each sample was dried and weighed to determine total dry plant matter produced and total dry kernel weight.

Results

One of the objectives of the study was to identify a simple gravity-fed drip system that could operate reliably, effectively and efficiently on the Navajo Nation. Observation of the working systems allowed appraisal of reliability and effectiveness of the systems in producing a corn crop. Comparison of harvest data with a surface irrigated plot at the Hubbell Trading Post location was done to determine if drip irrigation was an efficient means of irrigation in corn production. To accomplish this, harvest weights from the drip irrigated plots were compared to harvest weights from the surface irrigated plot.

Soil and Water Analysis

Soil samples from the Hubbell Trading Post were analyzed for soil texture using the Bouyoucos Method (Calgon Hydrometer). Two sets of samples were taken to an augured depth of 150 cm in the center of both the surface irrigated plot and the drip irrigated plots. Analysis of the soil samples yielded the results shown in table 1.

Table 1: Results of Hubbell Trading Post soil analysis using the Calgon Hydrometer

Plot	Sample Depth	% Sand	% Clay	% Silt	Soil Texture (Bouyoucos Method)
Drip Plot	0-15 cm	41	45	15	Clay
	15-30 cm	41	43	17	Clay
	30-60 cm	26	50	25	Clay
	60-90 cm	0	76	25	Clay
	90 –120 cm	28	58	15	Clay
	120-150 cm	33	50	17	Clay
Surface Plot	0-15 cm	46	43	12	Sandy Clay
	15-30 cm	44	45	12	Clay
	30-60 cm	44	43	14	Clay
	60-90 cm	0	68	32	Clay
	90 –120 cm	0	76	24	Clay
	120-150 cm	49	38	14	Sandy Clay

These results, when plotted on a standard USDA soil texture classification triangle determined the soil type to be mainly clay textured with some sandy-clay soil texture evident from surface to a depth of 15 cm and from 120 cm to 150 cm. The same soil samples were analyzed for soil EC and results are shown in table 2.

Table 2: Results of Hubbell Trading Post soil analysis for soil EC.

Sample	Depth (cm)	Soil EC (dS/m)
Surface Plot	10 – 15	0.40
	15 – 30	0.28
	30 – 60	0.29
	60 – 90	0.58
	90 – 120	0.32
	120 – 150	0.59
Drip Plots	10 – 15	0.34
	15 – 30	0.28
	30 – 60	0.29
	60 – 90	0.39
	90 – 120	0.69
	120 – 150	0.66

The results of the soil EC data show that the soil does not represent a significant concern with respect to salt content for corn production. According to Ayers and Westcot (1994), corn can be grown in soil with an EC of 1.7 dS/m without any reduction in yield. Table 3 shows the EC data recorded for the irrigation water used at Hubbell.

Table 3: Electrical Conductivity (EC) measurements on water samples.

Site	Hubbell Drip Irrigation	Hubbell Surface Irrigation
Water Source	Ganado Reservoir	Ganado Reservoir
2005 EC (dS/m)	0.37	NA
2006 EC (dS/m)	0.24	0.33

NA = Not available

Irrigation Water Applications

The daily water applications for the drip plots were calculated according to a maximum daily requirement for hybrid corn of 0.71 cm per day for the month of July (NMSU, 2005). Irrigation data from the New Mexico State University Plant Science Extension service was used, which is based on cultivation of hybrid varieties at Farmington, NM. This was the closest comparable site growing corn for which published data were available.

The 200-L drum was used in order to supply the daily irrigation requirement of 0.71 cm to the drip irrigated plots with one fill of the drum per day. After planting, the automatic timers were set to fill the drums once each day. In 2005 it became evident from wilting that plants were not receiving adequate water and the timers were reset on July 20th to supply two drums per day (Day 36 after planting). On scouting the field, morphological symptoms such as leaf rolling, limp leaves and dry soil in the top five centimeters were taken as indicators of moisture stress. In order to maintain similar conditions on all three drip plots, it was easier to control water applications by complete drum fills rather than by a timed interval, as the three systems operated at different rates of fill. Irrigating with two drum fills per day amounted to a daily irrigation depth of 1.42 cm.

Due to plugging of the drip tape in the second half of the season which caused the drums to drain more slowly through the drip tape, as well as blockages in the filter systems and supply, the practice of using two drums per day was continued to harvest in order to supply sufficient water to the crop. Figure 17 shows the cumulative water applied for the three Hubbell drip irrigated sites in 2005. Irrigation of the Hubbell surface irrigated plot could only be estimated from the number of irrigation events and the estimated depth irrigated on each event as no water metering device was used and staff were unfamiliar with the gated pipe system which caused some flooding in early season, as well as making it difficult to calculate precise delivery rates. A total 991 mm irrigation water (estimated) was applied during the season.

In 2006, an attempt was made to be more efficient with irrigation scheduling. The timers were initially set to supply one drum per day after planting. It was thought that this would be increased to two drums per day in mid season and back to one drum per day in late season. Research was done into daily water use by corn by stage of development. Figure 18 shows a daily consumptive water use curve for corn (Evans et al, 1996). On this curve, a sharp increase in water use is noted when the corn reaches knee height. There is a higher consumptive water use throughout the vegetative growth phase, tasseling, silking and production of the corn ear. Following this curve, irrigation frequency was increased from one drum per day to two per day on August 7th 2006 (Day 47 after planting). Due to plugging of the drip emitters the daily water applied to the plots was restricted and the irrigation frequency was maintained at two drums per day in order to supply sufficient water to the plants.

Figure 19a and 19b show the cumulative water applied for the three drip irrigated sites in 2006. On day 46 the water meter for Drip System 1 was installed backwards by mistake after cleaning and the meter counted backwards until day 62 at which point it was installed correctly again. The meter appeared to then count higher flow than normal. The numbers reported for Drip System 1 between day 46 and day 76 are estimated based on meter readings prior to day 46. Figure 19a shows the actual readings for the drip systems and Figure 19b shows the actual readings for drip systems 2 and 3 and the estimated readings for drip system 1.

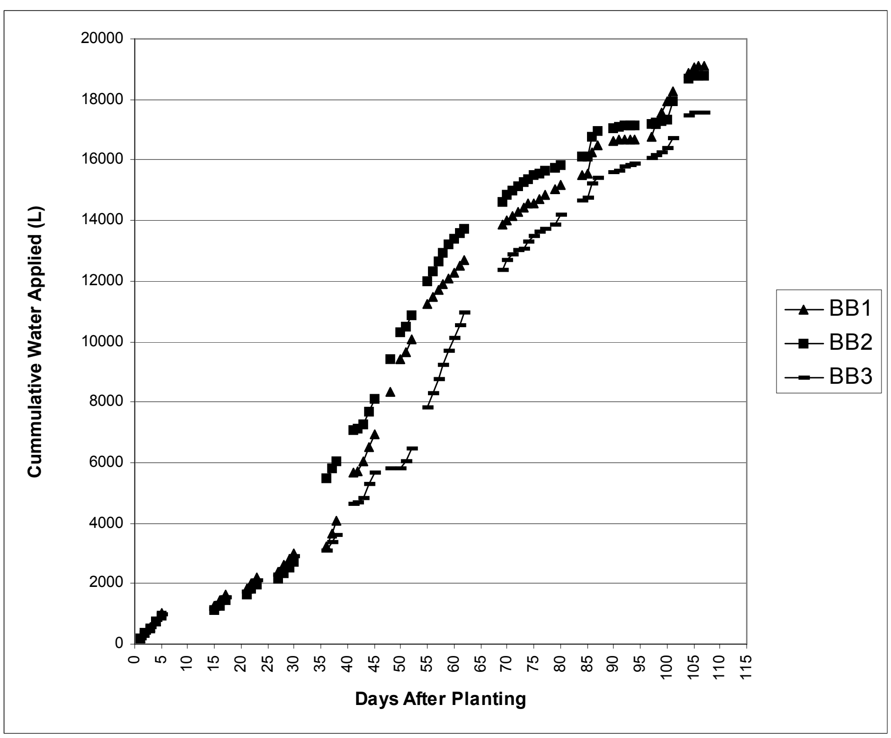


Figure 17: Cumulative water applied for Hubbell Drip Systems 1 through 3 in 2005. BB1= Hubbell Drip Plot 1, BB2=Hubbell Drip plot 2, BB3=Hubbell Drip plot 3.

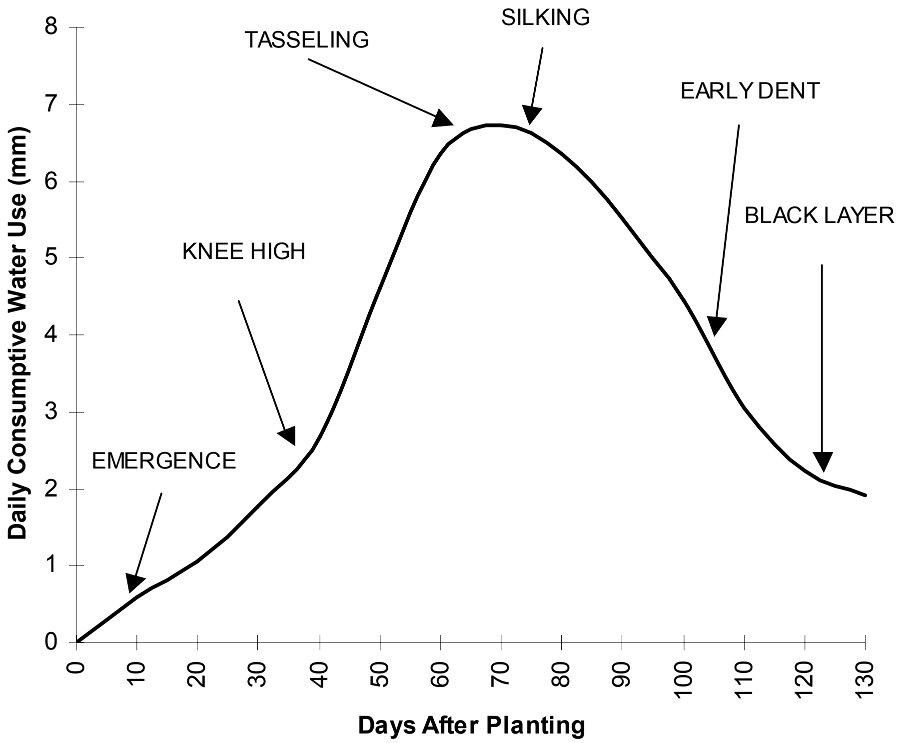


Figure 18: Daily consumptive water use for corn (Modified from Evans et al, 1996).

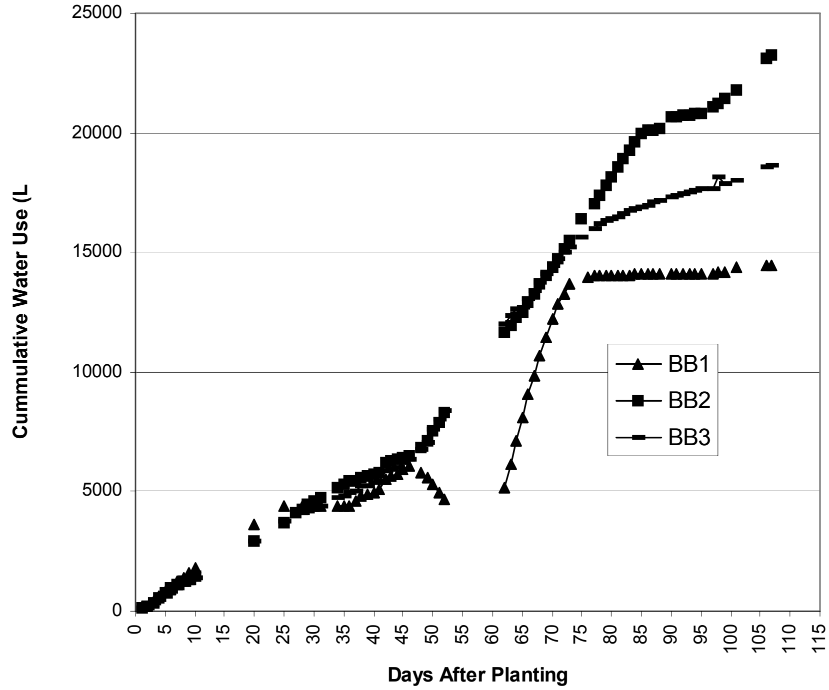
Irrigation scheduling for the Hubbell surface irrigated field was carried out according to the needs of the crop. In 2005 the field was flood irrigated. As this was the first season of cultivation for many decades, the newly formed terraces were not perfectly level and it was difficult to irrigate evenly and with complete control. Some flooding occurred from adjacent terraces. An estimated 991 mm was applied to the field over 6 irrigation events throughout the season. In 2006 a more accurate system of measurement was installed which used a single inlet to the field through a water meter. In this way, PVC piping was used to supply individual furrows with water through individual valves. The total water applied to the plots is given in Table 4.

Table 4: Irrigation water applied for all plots during 2005 and 2006.

Site	Water applied 2005 (mm)	Water applied 2006 (mm)
Hubbell drip plot 1	686	591*
Hubbell drip plot 2	674	844
Hubbell drip plot 3	630	677
Hubbell surface plot	990	533

*Estimated

(a)



(b)

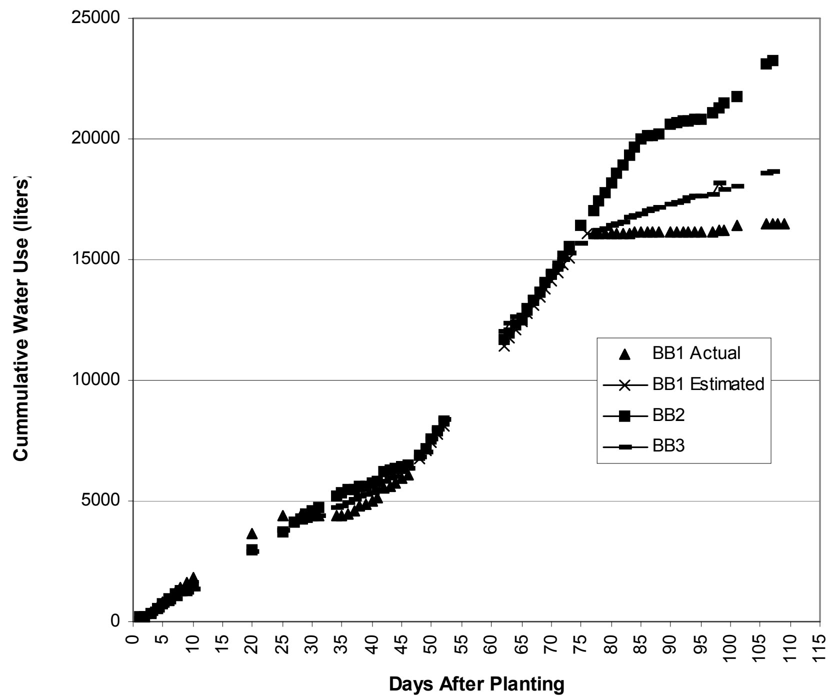


Figure 19: (a) Cumulative water applied for Hubbell Drip Systems 1 through 3 in 2006 based on actual meter readings. BB1= Hubbell Drip Plot 1, BB2=Hubbell Drip plot 2, BB3=Hubbell Drip plot 3; (b) Cumulative water applied for Hubbell drip systems 1 through 3 in 2006 based on actual meter readings (BB2 and BB3), and estimated readings for BB1. BB1= Hubbell Drip Plot 1, BB2=Hubbell Drip plot 2, BB3=Hubbell Drip plot 3.

A measured total of 533 mm was applied evenly to the field throughout the season using this method. Although this system allowed for more accurate measurement of water applied, it may not have represented a traditional surface irrigated system.

Harvest Data Analysis

Harvest yield data for both seasons is presented in table 5. The grain weight per hectare was obtained by multiplying the grain weight obtained from the two-meter sample of crop row to give a proportional yield per hectare. The area associated with a two-meter sample of a crop row was calculated as a two-meter length of row multiplied by a row width of 0.90m to give 1.8 m² for each sample. All five rows of each plot were sampled in entirety. The yield from the entire 27 m² of plot was totaled for the five rows and this total yield was converted to a yield per hectare.

A combination plot showing water applied data with yield data for 2005 and 2006 for each plot is shown in figure 20a and b. In 2005, average yields of grain per hectare, per mm of water applied (including rainfall) of 3.70 kg/ha/mm and 4.86 kg/ha/mm were achieved for the surface and drip plots respectively. In 2006, yields of 4.90 kg/ha/mm and 4.07 kg/ha/mm (including rainfall) were achieved for the surface and drip irrigated plots respectively. Average yields per mm applied (including rainfall) over both years were 4.30 kg/ha/mm for the surface irrigated plot and 4.47 kg/ha/mm for the drip irrigated plot. Ganado rainfall data shows 93 mm of precipitation during the 2005 season and 140 mm during the 2006 season.

Table 5: Harvest yields of grain in kilograms per hectare for 2005 and 2006, Hubbell site.

Site	2005 Yield (kg/ha)	2006 Yield (kg/ha)
Hubbell Drip 1 plot	4339	2891
Hubbell Drip 2 plot	3862	3301
Hubbell Drip 3 plot	2822	4109
Hubbell Surface plot – sample 1	3767	3071
Hubbell Surface plot – sample 2	3337	3776
Hubbell Surface plot – sample 3	4930	3055

CONCLUSIONS AND RECOMMENDATIONS

The objectives of the research project were achieved firstly by designing a water supply system using simple methods and low cost components for growing corn using gravity-fed drip irrigation tape. Secondly, the implementation was successful at the Hubbell Trading Post where three research systems were operated alongside a conventional surface irrigated plot over two seasons using the upgraded Ganado reservoir and irrigation supply pipeline. Finally, the demonstration aspect of the project was achieved by stimulating local interest through operating the research plots in a highly

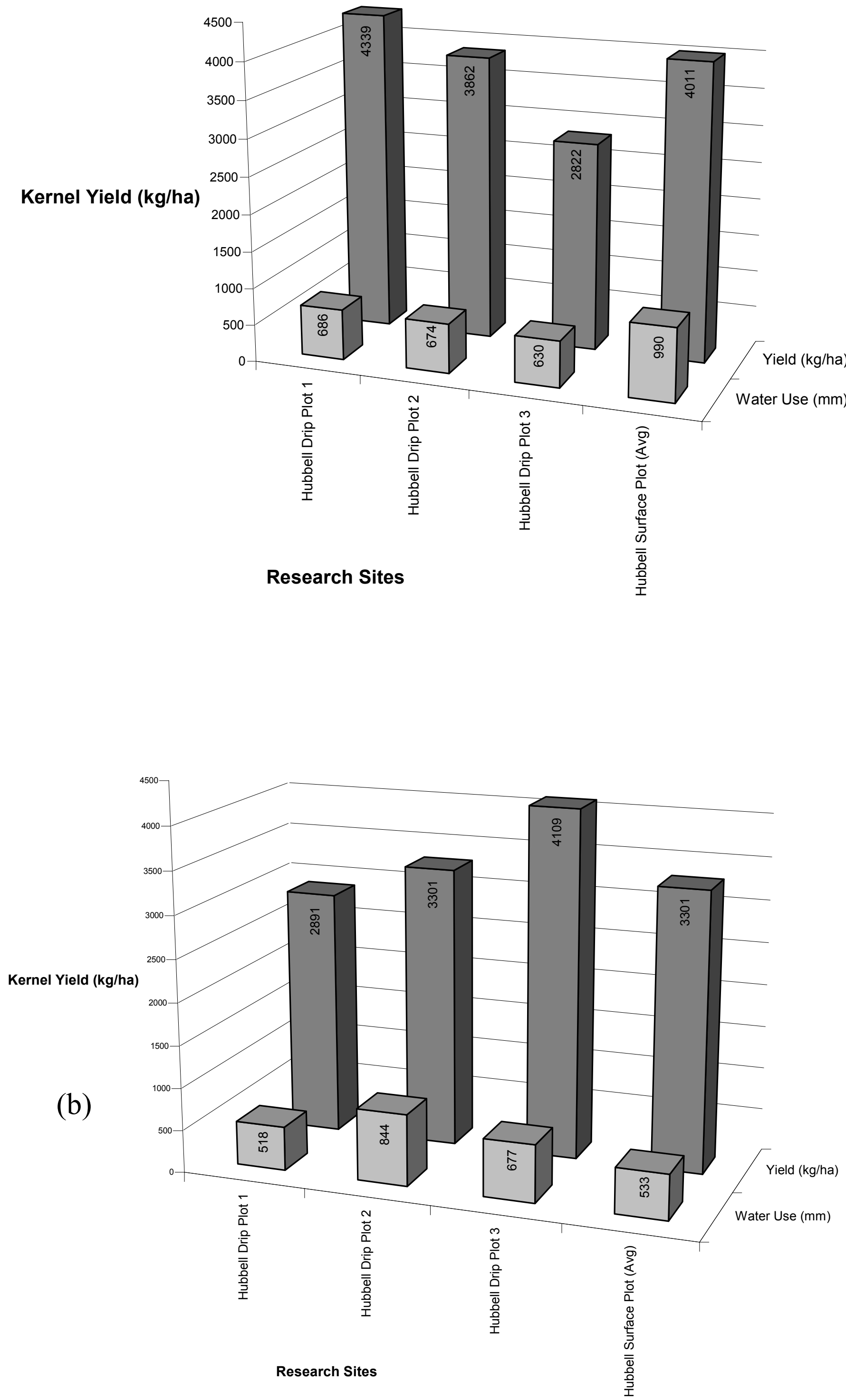


Figure 20: (a) Water applied (mm) vs. yield (kg/ha) for all plots 2005; (b) 2006.

visible location and by involving Hubbell Trading Post staff in the setup and planting as well as in the operation, maintenance and data collection.

Operation of System

The watering systems and drip tape operated reliably over two seasons with very little maintenance and very low labor input. However, water quality was seen to have a major effect on the operation of the system. In particular, blockages caused by plastic film and algae in the many flow orifices associated with the water meter, filters and timer devices on each drip system caused the greatest problems. The drip tape experienced emitter blockage by salt accumulations when used with lower quality irrigation water and by algae when using chemically untreated source water. The manufacturers claims of good self cleaning properties resulting from the turbulent flow regimes generated in the drip tape emitters are designed to remove particulate matter. Algae and salt accumulations cannot be controlled in this way.

All the drum systems operated reliably and effectively throughout each season. The systems stood up well to the natural elements, and no mechanical failures were seen. Minor leaks in the drip tape associated with rodent damage were easy to repair and did not cause problems to the overall operation. All connections and valves, including the battery operated timers operated flawlessly throughout each season. In addition, the systems were easy to build and all parts were easy to source. As a maximum of two drum-fills were used per day it would be possible to operate the system in the absence of a piped water supply by hauling water to the plot.

Corn was chosen solely for the importance of this crop to the Navajo way of life. However, corn is a relatively high water-use crop. The development of such a large plant, with a high amount of leaf mass demands more water than a smaller vegetable plant. For this reason the daily watering requirements were relatively high for such a small plot. Acceptable yields of corn were produced which was one of the aims of the study.

Comparison of Yields

In general, yields for the Hubbell drip plots and the Hubbell surface irrigated plots were similar. Irrespective of irrigation method used, higher water use showed a higher yield. Comparing the grain produced per mm of irrigation water applied in both years, the drip plots were seen to have effectively the same production per mm as the surface plot. This showed that corn could be produced with similar efficiency to surface irrigation using drip irrigation methods.

Demonstration

The bucket drip irrigation project intended to show interested people that possibilities exist for small farms and gardens to produce crops even without a piped water supply. The potential for information transfer was excellent given the location of the study. The site was visible to visitors to the National Park and the public, both of who are free to walk the grounds of the historic site. The Hubbell Trading Post staff was trained in operating and maintaining the system on a daily basis. The irrigation systems were demonstrated as part of the regular interpretive tours given during the summer months and field days were held during the growing season when local residents were allowed to collect pollen from the plants for ceremonial use. At harvest time, Hubbell Trading Post staff shared the ears of corn with local residents.

In connection with this project, numerous presentations and talks on the simple drip irrigation systems have been made throughout the Navajo Nation: at local Ganado Schools, the Navajo National Farm Board Meetings and other Navajo local events. Additional exposure was received by a presentation made at a sustainability workshop, attended by a number of Navajo smallholders and other interested parties. Other interest has been stimulated at Diné College located in Tsaile, AZ, the first tribally controlled college in the United States, where College students collaborated to play different roles in their own simple drip irrigation project, using one of the same systems that were used at the Hubbell Trading Post.

Working at the Hubbell Trading Post allowed us to easily attain temporary use of a plot of land for research and demonstration purposes, and provided much help with field preparation, planting, harvesting and regular data recording. It would have been difficult to establish the same infrastructure in a short time without the help of the Hubbell Trading Post staff.

Furthermore, in addition to the research plots a demonstration plot was established using a small scale version of the bucket drip system to grow corn over three seasons (2004-2006) on the site of the original Hubbell Trading Post kitchen garden. In this demonstration, three 20 L buckets were each connected to a 24 m length of drip emitter tubing, which served as an example of a simpler alternative to the larger system installed for research purposes in 2005 and 2006. The study played a small role in the overall picture of bringing agriculture back to the Hubbell Trading Post after an absence of many years, and stimulating a general interest in agriculture in the Ganado area.

In 2007, bucket drip or variations of that system, can be seen throughout the western Navajo Nation. At the Hubbell Trading Post, the drip systems are being used in the kitchen garden. At Tsaile, three large drip plots are being used at Dine College. In Chinle, just North of Ganado, there are three drip demonstration gardens at the Regional hospital, promoting water conservation and healthy eating. A large 500 m^2 drip plot is being used within Canyon de Chelly, along with a traditional big bucket system. Finally, a local group called the Canyon Farmers (growers who cultivate inside Canyon de Chelly) requested 50 small bucket drip kits from Chapin. The kits were donated by Dick Chapin and have been distributed to interested people throughout Chinle and Canyon de Chelly.

Recommendations

The use of an adequate filtration system was found to be crucial in maintaining a steady flow of water through the system. A single large filter provided much easier maintenance than single filters located on each separate system. This limited the number of connections to be broken for cleaning purposes and controlled the build-up of debris on the individual filters in the meter and timer. As well as reducing the general maintenance requirement there is also less chance of components being incorrectly reinserted or badly connected.

Means of reducing algal growth could include painting the drums to make them opaque and periodic treatment with a disinfectant such as chlorine. In order to actively attack the problem the drums could be filled with a disinfectant solution and allowed to soak before being carefully flushed out. This was not possible during the study due to time constraints as well as the absence of a disposal point for the disinfectant solution and it was not thought advisable to have disinfectant solution draining to the plot.

Daily observation of the system proved to be an important factor in ensuring reliable operation, which was not always possible during the study. In this way, problems such as having valves closed by outside parties, or valves closed for maintenance and not re-opened are easily caught before the plants begin to suffer a lack of water. Other problems such as timer mechanisms not operating due to low battery power, plugging of components with debris or algae, and wrongly inserted components could be identified quickly. The simplest check is to observe the drum filling, as well as emptying to the drip tape. This would ensure that both the water supply and the flow to the drip tape were operating correctly.

Typically drip tape should last for a few years with a little maintenance after each season. At all sites minor damage occurred as a result of rodents. This damage was easily repaired using waterproof tape. Algae only seemed to cause emitter plugging in the drip tape towards the end of the growth season. Flushing the drip tape could reduce plugging problems. This is achieved by opening the ends of the drip tape lengths and flushing through either with water or a disinfecting solution to remove biological growth. In addition an acidic solution can be used to dissolve accumulated calcium deposits. A dilute acid flush was attempted in the first season at Maricopa when calcium deposits were observed around the emitters with little effect, and it was found easier to replace the drip tape. The drip tape used is low cost and the fact that it is used in a surface application makes replacing it a simple operation. Commercial growers use regular acid flushes to avoid problems of salt accumulations in emitters. This requires a regular supply of chemicals and the correct handling and control of these. As this study was aimed at simplicity and rural applications, these methods were not considered further in this study. Use of subsurface drip irrigation may also reduce plugging problems due to lower ambient temperatures around the drip tape, as well as lower evaporation rates than those seen at the soil surface.

A certain amount of site preparation is required. To ensure uniformity of emitter flow it is recommended that the growing area be leveled as well as possible prior to planting. Other agricultural considerations such as tillage of the soil and application of fertilizer are not discussed in detail here but may be of importance depending on soil type and condition. Protection of the plot from animals, which may damage both the crop and the equipment, may be necessary. In particular, rodent damage was seen on plastic components and drip tape.

Growing a high water use crop such as corn on a simple system such as used in this study meant that a relatively high amount of water was applied to a small plot. If a low water-use crop was chosen, the plot could either be expanded for the same daily use of water, or alternatively, less water could be applied to the same size of plot. Depending on the available water supply method either of these alternatives may be worthy of consideration.

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