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WIND-POWERED DRIP IRRIGATION SYSTEMS FOR FRUIT TREES

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Summary:
The feasibility of using a wind-electric drip irrigation system for watering fruit and nut trees at 3 locations in Texas was analyzed using either a 1.5 or 10 kW wind turbine. Pumping performance data collected at Bushland was used with measured wind speed distributions for each location. With no storage capacity or pre-watering, only 0.1 ha of deciduous fruit trees could be watered with the 1.5 kW system; however, the area was increased to 1 ha with storage. A 10 kW system was required for watering mature pecan trees in Lubbock county and either system could meet the water requirements for citrus in Hidalgo county.

Keywords:
Wind energy, drip irrigation, water pumping, wind power, irrigation, trees

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ABSTRACT

The feasibility of using a wind-electric drip irrigation system for watering fruit and nut trees at 3 different locations in Texas was analyzed. Two wind-electric systems (a 1.5 kW and a 10 kW) have been extensively tested at Bushland for several years, so flow rate as a function of wind speed and pumping depth has been determined for several different pumps. Using these pumping performance data with measured wind distributions in the 3 locations together with the measured water requirements of each tree species, the overall effectiveness of the wind-electric drip irrigation systems were evaluated. With no storage capability or pre-watering, only 0.1 ha of deciduous fruit trees could be watered with the 1.5 kW system in the Eastern Texas Panhandle with a tower height of 18.5 m and a pumping depth of 40 m. However, if water could be stored or the land could be pre-watered in the windier months, 0.5 to 1.0 ha could be watered. Also increasing the tower height from 18.5 m to 40 m can result in 2 to 3 times as many trees that can be watered. The additional cost in tower height was more than offset by the increased area of irrigation. Using the 10 kW unit on a 50 m tower, 3.5 ha of pecan trees could be watered from a well with a 45 m pumping depth in Lubbock Co., TX. Although the feasibility of locating a wind-electric drip irrigation system in the Rio Grande Valley for irrigating citrus fruit was expected to be the least successful of the three systems because of the lower wind speed regime, this system appears to be the most economical because of the low pumping head requirements and a good match between citrus fruit tree monthly water demand and the wind speed monthly distribution.

INTRODUCTION

Combining a wind-electric system with a drip irrigation system for watering fruit and nut trees may open up vast regions of land heretofore untapped due to no utility supplied electricity. A wind-electric system is composed of a wind turbine, controller, tower, submersible motor, and centrifugal pump. The drip irrigation system is composed of a lateral pipe (either rigid or flexible) from the well or water storage tank to each row of trees with drip tubing for individual rows connected to the lateral pipe. One or more emitters are located at each tree. Stand-alone wind-electric water pumping research began at the USDA Conservation and Production Research Laboratory, Bushland, TX, in 1988 with a 10 kW wind-electric system. Ten years of testing this system for water pumping has been previously reported (Vick et al, 1998). Also, many pumps at different pumping depths have been tested on a 1.5 kW wind-electric system over the past several years (Clark et al, 1999). The 10 kW wind turbines were tested for irrigating cotton at two locations in central Texas (Vick et al, 1997).

Field experience gained from the 10 kW systems irrigating cotton and a 1.5 kW system watering 100 head of cattle in Bushland (Vick et al, 1999) led to one of the authors installing a 1.5 kW wind-electric system on the highest point of his farm in Wheeler Co. in 1998. In the early part of 1999 an orchard of deciduous fruit trees (apples, peaches, etc) were planted about 25 m down the hill from the well and the wind-electric system. Later in 1999 a drip irrigation system was installed. A 3785 liter (1000 gallon) storage tank was placed between the well and the orchard in order to increase the pressure in the system in order to overcome the 6.9 kP(1 psig) pressure required for operation of the low pressure emitters. The storage tank is located on the top of the hill and the trees are watered using gravity feed. While the wind-electric system can maintain pressure in moderate to high winds it can not in low to moderate winds if no storage tank is included. In the beginning of 2000, additional deciduous trees were planted bringing the total to 130 trees on approximately one ha (2.5 ac) of land (9.1 m spacing between the trees).

Another farmer growing 700 fully mature pecan trees on 16.2 ha (40 ac) of land in Lubbock county was interested in using a wind turbine to pump water for his pecan trees. He already had access to utility electricity, but thought the intermittent nature of the wind would be better for irrigating his trees. He also already had installed a drip system for his trees. The 10 kW wind-electric system was evaluated for pumping water to meet the water requirements of his orchard.

We also wanted to evaluate the use of wind-electric drip systems for citrus orchards. The closest citrus orchard to our location was in Hidalgo Co. in the Rio Grande Valley, and since wind data had been collected close to this area for four years at different heights, evaluating a wind-electric drip system was possible.

RESULTS

For best evaluation of a wind-electric drip system, the wind speed needs to be measured at the hub height of the wind turbine and recorded as hourly distribution data. Figure 1 shows actual and estimated wind data collected for Wheeler Co., Lubbock Co., and Hidalgo Co. (all in Texas). By comparing the wind speeds at the same height over at least a one year period, one can determine the wind regime. The wind speed data in Wheeler Co. was collected from July/1998 until July/1999. The wind speed data shown for Lubbock Co. is actually data collected at a 40 m height from Jan./1996 until Jan./1999 in Amarillo. Based on some older data the wind speed in Lubbock is about 0.5 m/s less than that in Amarillo. This small change in wind speed can be modeled by increasing the height of the wind turbine by 10 m. Therefore, the Lubbock data is shown at a 50 m height instead of 40 m. The wind data shown for Hidalgo Co. was actually collected in Rio Grande City in Starr Co. from Aug./1995 until Jan./2000. However, the distance between Rio Grande City and the citrus orchards in Hidalgo Co. is only 50 km, so these wind speed data are expected to be representative of Hidalgo Co.

Extensive flow rate versus wind speed data for different pumps and pumping depths have been gathered for both the Bergey[1] 1500 (1.5 kW) and Bergey Excel (10 kW) wind-electric systems (Clark et al, 1999 and Vick et al, 1998, respectively). The flow rate data used to analyze the 1.5 kW wind-electric system in Wheeler Co. are shown in Figure 2. The flow rate data used to analyze the 10 kW wind-electric system in Lubbock Co. are shown in Figure 3. The flow rate data used to analyze both the 1.5 kW and 10 kW wind-electric systems in Hidalgo Co. are shown in Figure 4. The pumps used for evaluating the wind-electric drip systems in Wheeler Co. and Lubbock Co. had 15 stages while the pumps used for evaluating wind-electric systems in Hidalgo Co. had 3 and 1 stages respectively for the 1.5 kW and 10 kW wind turbines. More pump stages are required as the pumping depth increases and the pumping depth in Wheeler and Lubbock counties was about 40 m while that in Hidalgo county was estimated to be below 10 m. Multiplying the flow rate data in Figure 3 by the wind speed hourly distribution data (and dividing by the number of days in the month) produces the daily water volume data shown in Figure 5 for different heights in Lubbock Co. Multiplying the 10 kW data in Figure 4 by the wind speed hourly distribution data (again dividing the number of days in the month) produces the daily water volume data shown in Figure 6 for different heights in Hidalgo Co.

Besides water supplied by the wind-electric drip irrigation system, water is also supplied by precipitation. Figure 7 shows the monthly average precipitation for Wheeler, Lubbock, and Hidalgo counties. Hidalgo county has the highest total annual precipitation followed by Wheeler Co. -- Lubbock Co. has the lowest annual precipitation. Figure 8 illustrates the water requirement for optimal production from mature fruit and nut trees for the sites selected for evaluation of wind-electric drip irrigation systems. Although all three types of trees vary in their monthly water requirement, the total annual water requirement is almost the same. Although the monthly water requirement for deciduous fruit and pecans is similar (high water demand in summer and low water demand in fall and winter), the monthly water requirement for citrus fruits is much different (gradual increase in water demand from winter to spring to summer and then a gradual decrease in water demand to fall). The data shown in Figure 8 was obtained from tables from McDaniels et al, 1960.

Figures 9 through 14 show how well the wind-electric drip irrigation systems satisfy the water requirements of the trees. Figure 9 shows the maximum area of land (0.1 ha) that the 1.5 kW wind-electric system can supply for deciduous trees in Wheeler Co. to keep from having a monthly water deficit. Because the low wind speeds occur in the summer which also coincides with the largest water demand by the trees, the amount of trees that can be watered is much smaller than suspected. Figure 10 shows the daily water volume of the 1.5 kW unit in Wheeler Co. for the current size of the orchard – 1 ha. Although the monthly water deficit is obvious during the summer, there is actually an annual surplus of water of 653 m^3 (3.6 acre ft).

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[1] The mention of trade or manufacture names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA – Agricultural Research Service.

Therefore, if the water could be stored in an earthen dam during the winter and spring, this wind-electric drip system would be adequate. Also, increasing the tower height would help during the summer months, but since no additional wind data were available, prediction of increased performance due to height is difficult.

Figure 11 shows the maximum tree area (3.5 ha) that can be watered by a 10 kW wind-electric drip system in Lubbock Co., TX. Besides the Lubbock wind resource being better than the Wheeler wind resource, the 10 kW unit is mounted on a much taller tower 50 m compared to 18.5 m. Figure 12 shows the water deficit that would occur if the entire 16 ha pecan orchard was irrigated. Besides the water deficit being about three times the water pumped during the summer months, there is also an annual water deficit, so using an earthen dam storage wouldn't completely satisfy the water deficit. It would be better to install a larger wind turbine to meet the water requirement of this orchard – probably one rated at 40 to 50 kW.

Figures 13 and 14 show how wind-electric drip systems should perform in irrigating citrus orchards in Hidalgo county of the Rio Grande Valley of Texas. Figure 13 shows that 3.5 ha of citrus trees can be irrigated with the 1.5 kW wind turbine mounted on a 40 m tower without having any monthly water deficit. It was assumed that water would be pumped from the irrigation canals meaning the system would only have to overcome about a 10 m head. The low head meant a low stage pump could be used which implied a maximum flow rate of 250 ℓ/min compared to a maximum flow rate of only 60 ℓ/min in Wheeler Co.

Figure 14 shows that the 10 kW wind-electric drip system can irrigate 32 ha of citrus trees without incurring a water deficit during any month. A low head of 5 m was assumed which meant a low stage pump could be used which meant a maximum flow rate of 950 ℓ/min could be reached compared to a maximum flow rate of about 200 ℓ/min in Lubbock. Again, it was assumed that the wind turbine would be mounted on a 40 m tower.

COST OF WIND-ELECTRIC DRIP IRRIGATION SYSTEMS

For Wheeler Co., the cost of the 1.5 kW wind-electric system (wind turbine, 18.5 m Rohn[1] 25G tower, poly pipe in well, 1.1 kW 3-phase 230 V submersible motor, 0.75 kW 15-stage centrifugal pump) was about $8000. The cost of the drip system including the 3785 liter storage tank was about $1000 so the total cost of the wind-electric drip irrigation system was about $9000. This cost doesn't include the cost of installation.

For Lubbock Co., the 10 kW wind-electric system (wind turbine, 40 m Rohn 45G tower, 60 m of galvanized pipe, 5.8 kW 3-phase 230 V submersible motor, 3.8 kW 15-stage centrifugal pump) was about $35000. The cost of the drip system for 4 ha with a 11,355 liter storage tank is estimated to be about $10000. The total cost of this wind-electric drip irrigation system (not including installation) is estimated to be $45000.

In Hidalgo Co., both the performance of a 1.5 kW and 10 kW wind-electric systems were evaluated. For the 1.5 kW wind-electric system the cost is expected to be about $10000 ($2000 more than the 1.5 kW wind-electric system in Wheeler county because of the 40 m tower). The drip irrigation system for 3.5 ha is estimated to cost about $7000 including the 3785 liter storage tank which brings the total cost to $17000 (not including installation). The cost of the 10 kW wind-electric system should be less than the one in Lubbock Co. since 60 m of galvanized pipe are not included, so the cost should be about $31000. The drip system cost for 32 ha is estimated to be $56000, so the total cost of the wind-electric drip irrigation system is $87000 (not including installation or water storage tank if required).

Normally using a wind-electric system will not save the farmer money if he already has access to utility supplied electricity because the cost per kilowatt-hour by the utility is less than $0.10. However, if there is no utility power available, the cost of extending transmission lines (anywhere from $10000 to $25000 per km depending on what part of the country one is located) will make using a wind-electric system more economical

CONCLUSIONS

The low wind speeds during July, August, and September together with the high water requirement of the fruit and nut trees in the summer resulted in failure of the wind-electric systems for meeting the water requirements in two locations -- Wheeler Co. and Lubbock Co. The best performing wind-electric drip system was in Hidalgo Co. despite the lower wind regime. The advantages in using a wind-electric drip system in Hidalgo Co. for watering citrus trees included: 1) low pumping head (< 10 m) and 2) a lower water requirement during June, July, and August which matched the average wind speed.

Only 0.1 ha of land with fully mature deciduous fruit trees could be watered in Wheeler Co. when no monthly water deficit was allowed. However, when the actual water requirements of the entire orchard of 1 ha was estimated, the total amount of water pumped by the 1.5 kW unit over the entire year was more than the amount required by the trees. This implies that if there was some pre-watering in the spring and/or an earthen dam could be built to hold the water, then the water requirement of the trees could be met.

Irrigating the pecans in Lubbock Co. with the 10 kW unit was more successful in that 3.5 ha could be watered without incurring a monthly water demand deficit. However, when estimating the water requirements of the entire 16.2 ha pecan orchard, not only was there a monthly water deficit during the growing season, there was also a substantial water deficit at the end of the year which implies that a larger wind turbine is required -- probably one rated at 40 to 50 kW.

For a citrus orchard in Hidalgo county, both the 1.5 kW and 10 kW wind-electric systems were analyzed for being able to irrigate the trees. The 1.5 kW wind-electric drip system could irrigate 3.5 ha of citrus trees, and the 10 kW wind-electric drip system could irrigate 32 ha of citrus trees -- both systems could water this amount of trees without incurring any monthly water deficit!

Generally, it is always more economical to use utility supplied electricity instead of installing a wind-electric system. However, if utility electricity is not available, then it is definitely worth investigating a wind-electric system because transmission line extension in the U.S. varies from $10,000 to $25,000 per km. Most of the time it is more economical to install a wind turbine on a taller tower because of the increase in wind speed with height and the cubic relationship of wind power to wind speed. The months which are affected the most by tower height are the low wind months which in the Wheeler and Lubbock Co. cases are the biggest drawbacks of the systems. Lowering the cut-in wind speed of all the wind-electric systems would also greatly improve these systems. A newly designed 2 kW wind-electric system tested at the USDA-ARS Laboratory in Bushland had a lower cut-in wind speed and a higher system efficiency than the wind-electric systems used in this paper (Vick et al, 2000).

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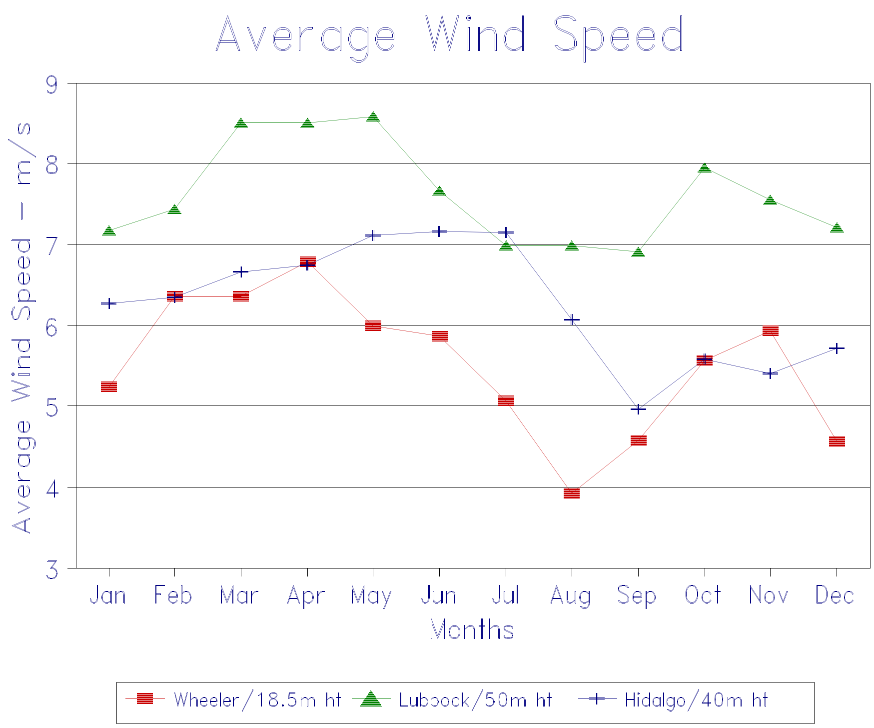

Figure 1. Monthly average wind speed at the 3 locations and the hub heights at which the wind-electric drip irrigation systems were analyzed.

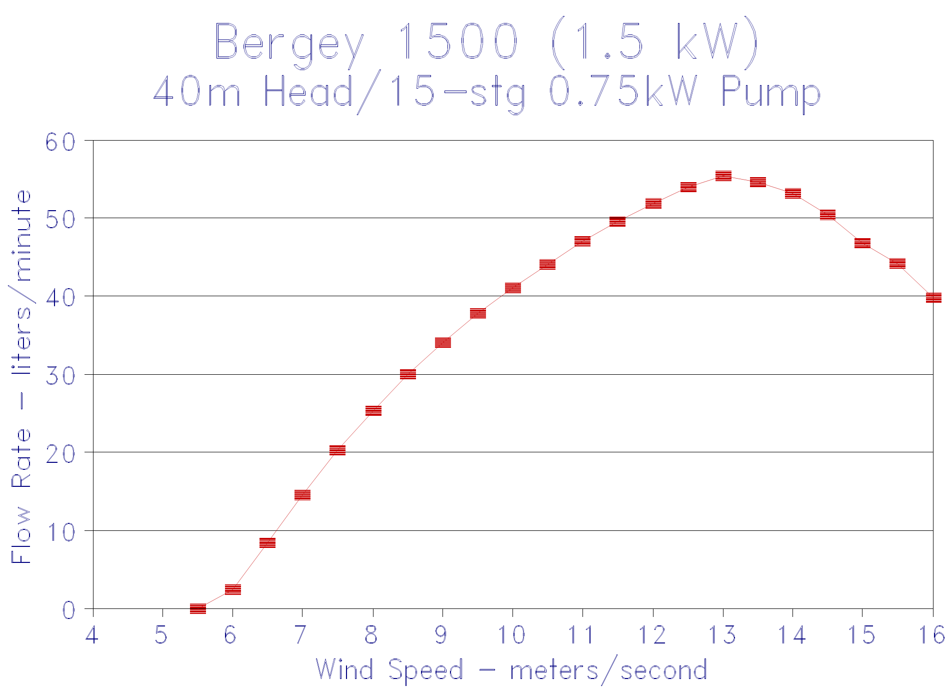

Figure 2. Flow rate of Bergey 1500 for a 40 m head with a 15-stage 0.75 kW pump.

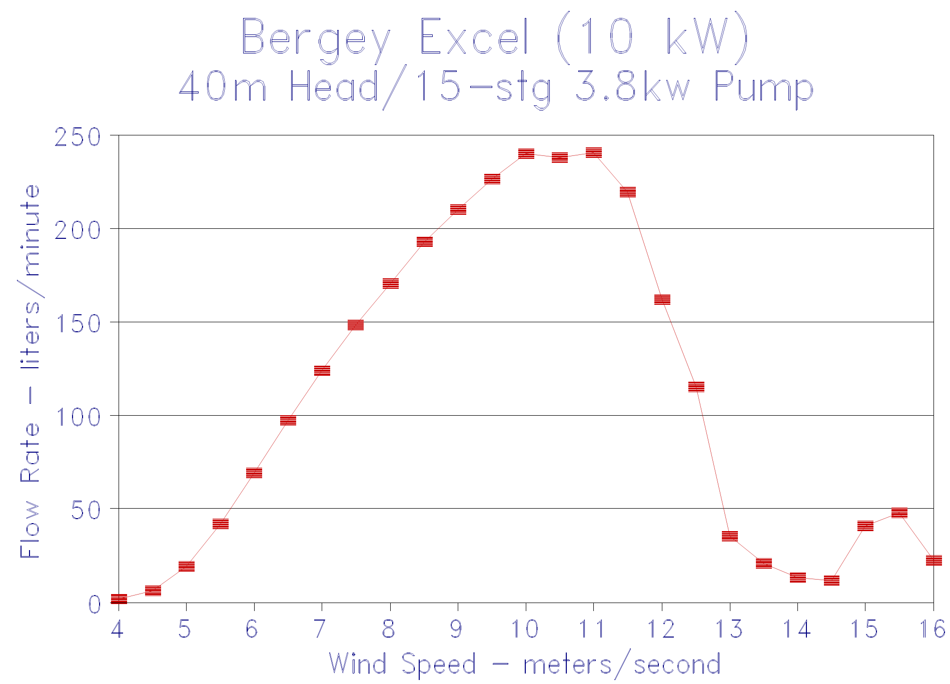

Figure 3. Flow rate of Bergey Excel (10 kW) for a 40m head and a 15-stage 3.8 kW pump.

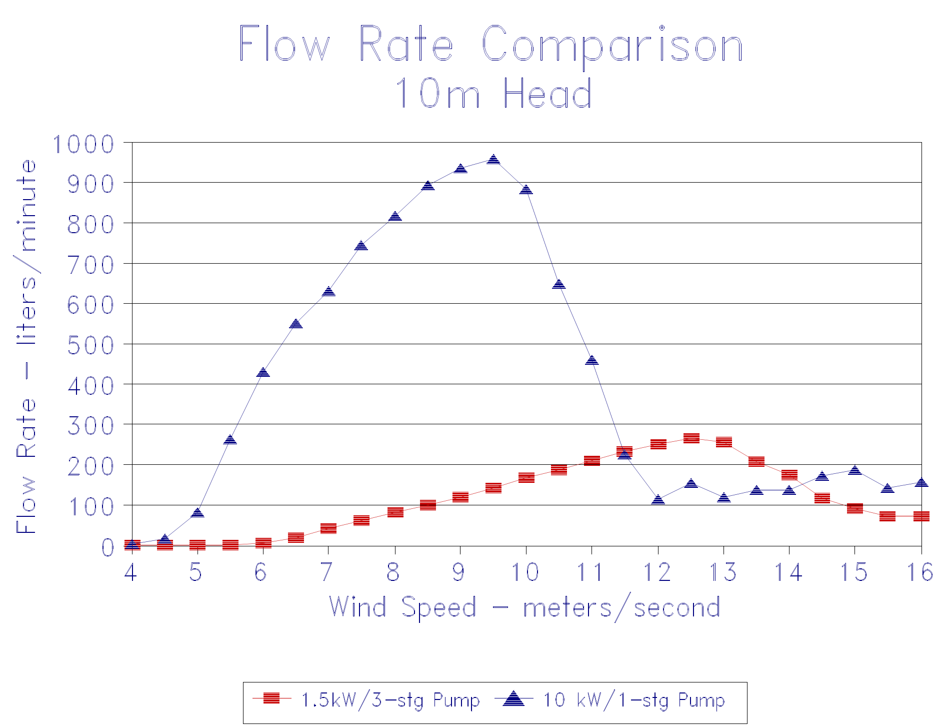

Figure 4. Flow rate comparison of low stage pumps on Bergey 1500 (1.5 kW) and Bergey Excel(10 kW).

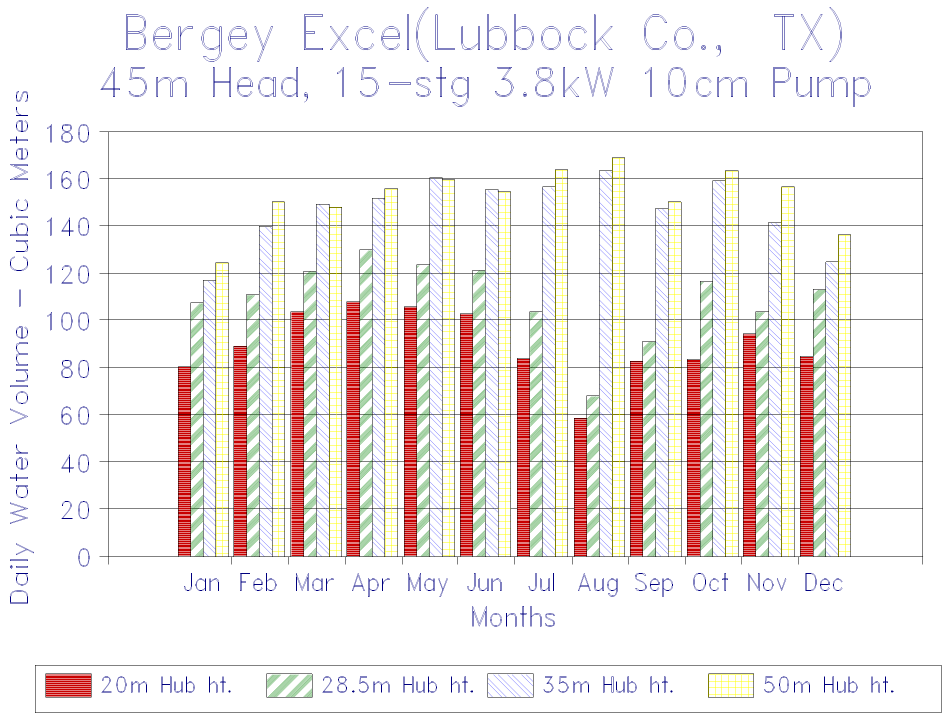

Figure 5. Effect of hub height on daily water volume for Bergey Excel in Lubbock county.

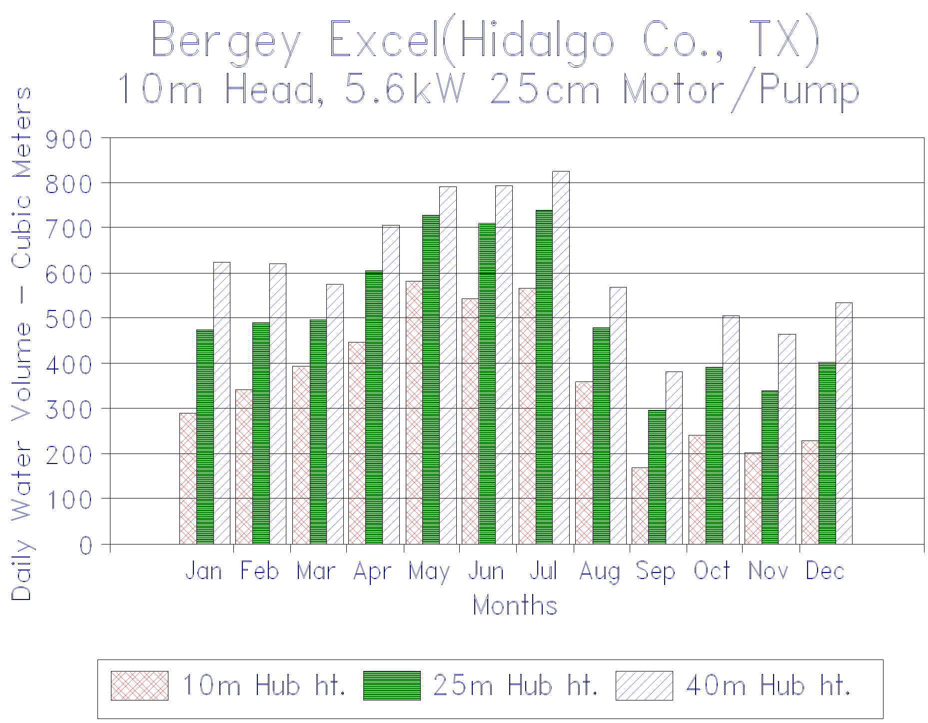

Figure 6. Effect of hub height on daily water volume of Bergey Excel in Hidalgo county.

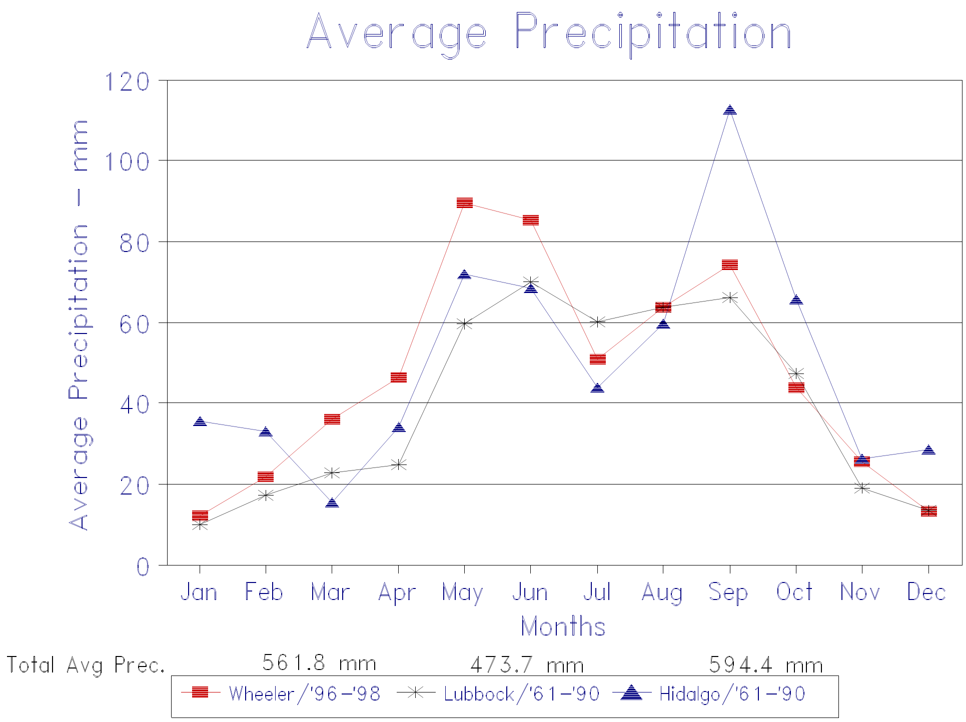

Figure 7. Average precipitation in the 3 counties analyzed for using wind-electric drip irrigation systems.

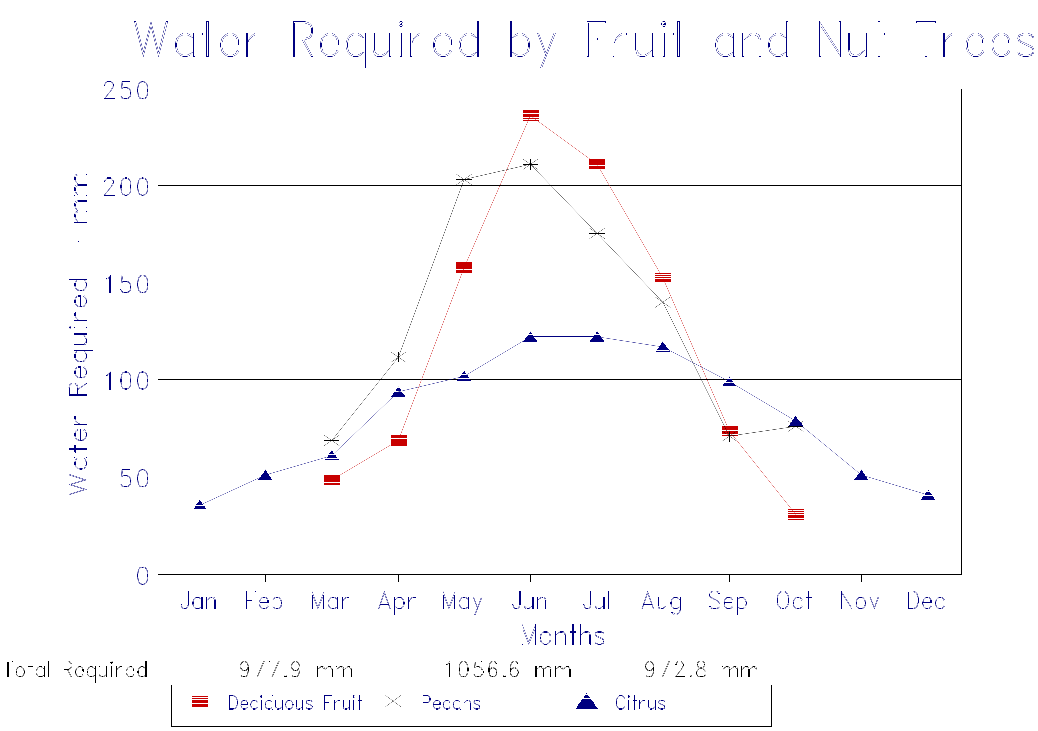

Figure 8. Optimum water required for three types of fruit and nut trees analyzed for using wind-electric drip irrigation systems.

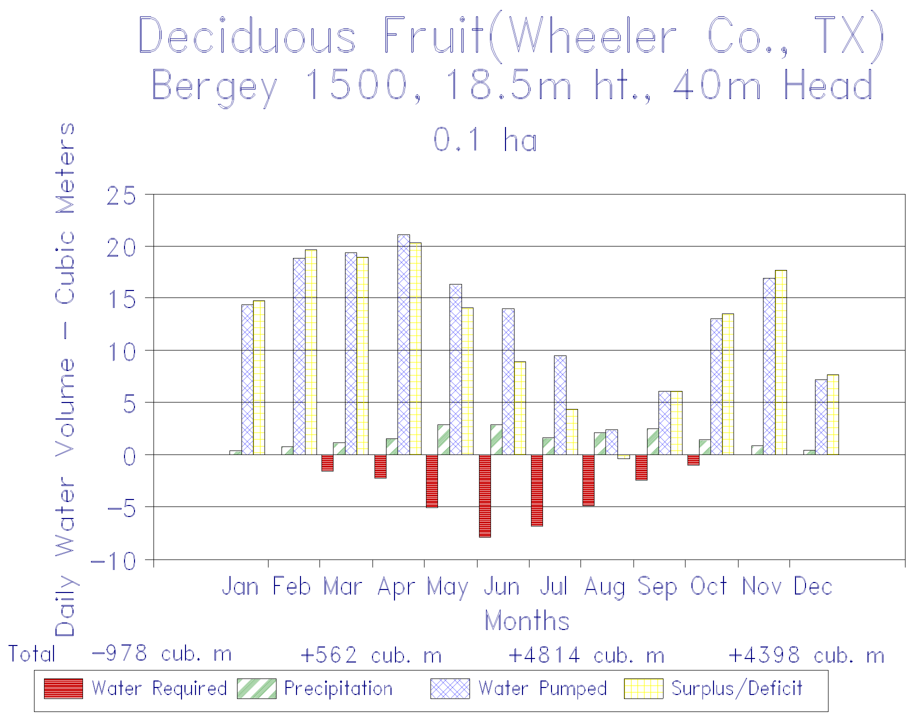

Figure 9. Maximum land area that can be irrigated by Bergey 1500 without incurring a monthly water deficit in Wheeler county.

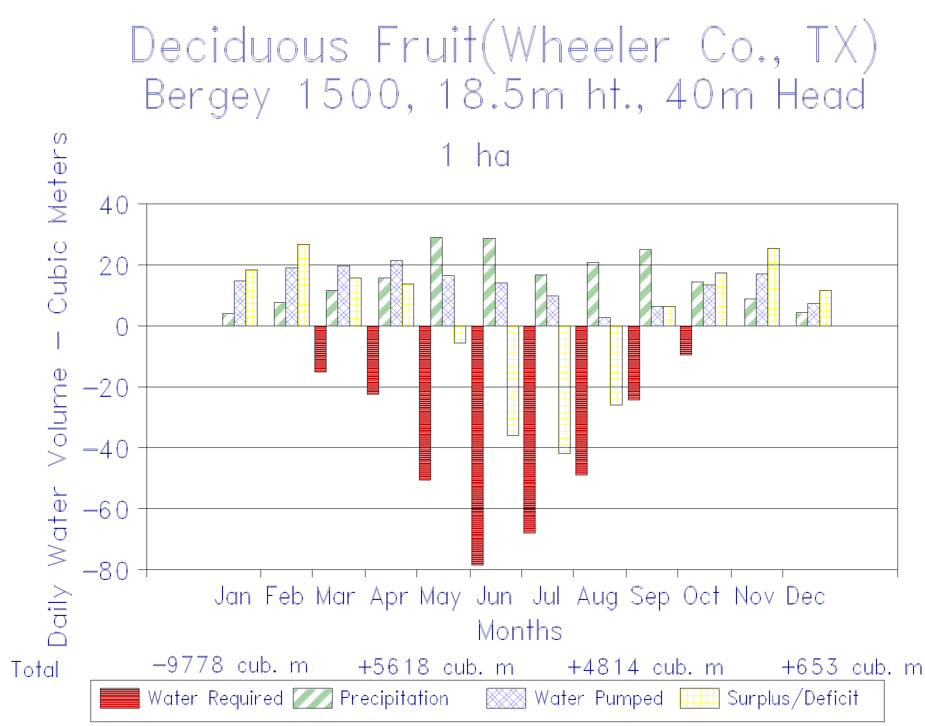

Figure 10. Effect on daily water volume when Bergey 1500 is used to irrigate entire orchard (note annual surplus of water).

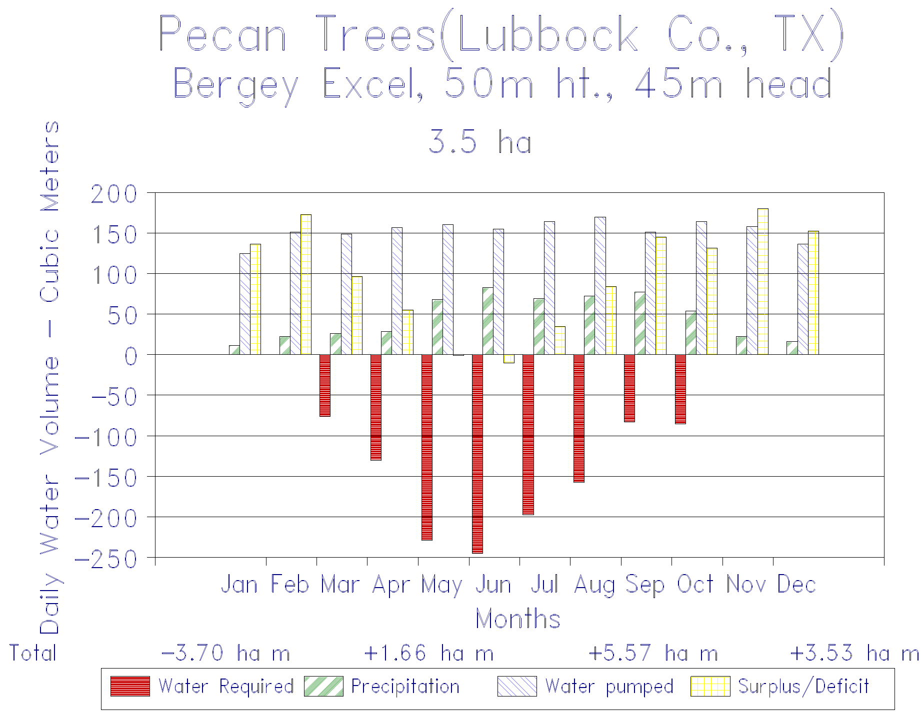

Figure 11. Amount of land area with pecan trees that the Bergey Excel can irrigate without incurring a monthly water deficit in Lubbock county.

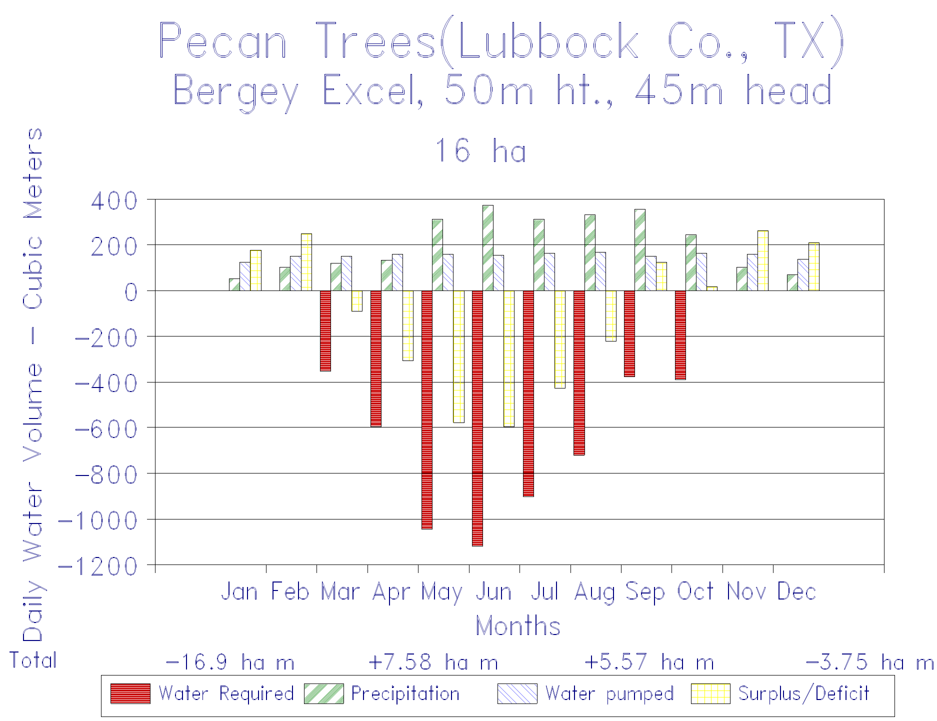

Figure 12. Effect on daily water volume when Bergey Excel is used to water the entire pecan orchard in Lubbock county.

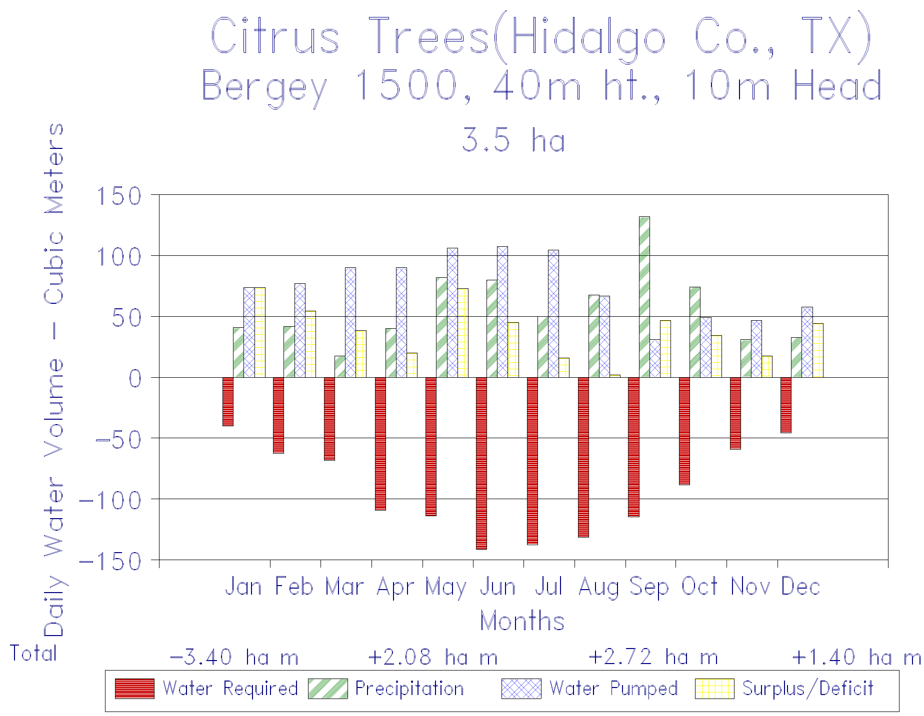

Figure 13. Maximum land area with citrus trees that the Bergey 1500 can irrigate without incurring a monthly water deficit in Hidalgo county.

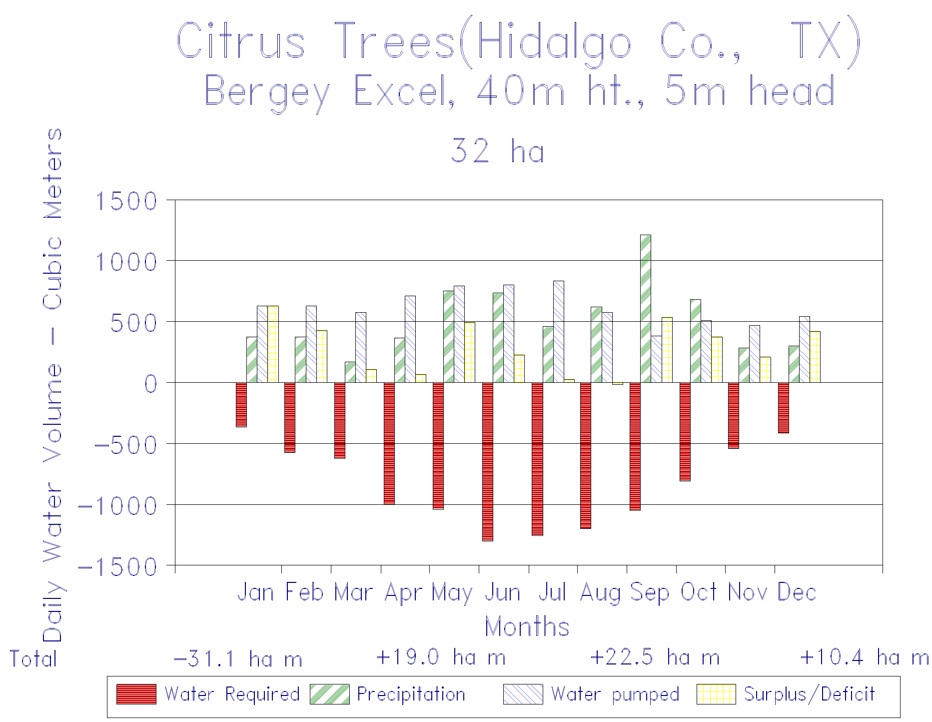

Figure 14. Maximum land area can irrigate with Bergey Excel without incurring a monthly water deficit in Hidalgo county.