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Partial Root Zone Drying Application in the Propagation of Vegetable in Northern Nigeria

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Abstract. This study compares the response of *Amaranthus candatus* vegetable to root-to-shoot signals of soil drying and assesses applicability of the use of partial root zone drying (PRD) technique in increasing water-use efficiency. From a completely block randomized design, seeds were grown on three plots with each having three replicates. Three treatments were compared: half of the root system watered and half droughted by delivering 50% less crop water requirement (CWR) per irrigation depicted as 50%PRD; both halves of the root system received water application of 50% less crop water requirement per irrigation (50%CWR); while in the control treatment, both halves received 100% crop water requirement (100%CWR). The wetted and dried sides of the root system of 50%PRD were alternated on a 7-day cycle throughout experimental period. Effects of the differences in water-use on growth parameters, such as plant height, stem girth; number of leaves and leaf area were examined. Weights at harvest and root-to-shoot ratios were also compared. Drying half of the root system caused marked declines in all growth parameters in 50%CWR but only slight declines in 50%PRD. Since the main effect of water stress on Amaranthus is yield reduction, achieving better yields requires an optimum water supply from planting until ripening. Average edible wet weights (yields) of the 50%PRD and 50%CWR water applications when compared with the control were 81% and 25% respectively. The higher yield in 50%PRD may be attributed to high stomata sensitivity to drought signaling, as indicated by relatively low root to shoot ratio of 0.33. This lower ratio for 50%PRD treatment, compared to 50%CWR and 100%CWR with 0.40 and 0.66 values, was an indication of healthier and more profitable plants in 50%PRD because the decrease came from a greater shoot size.

Introduction

Sokoto state was one of the largest states in Nigeria until Kebbi and Zamfara states were carved out from it. It lies between longitudes 11^0-13^0E and latitudes 4^0-6^0N, which is within the Sahel Savanna. The rainfall is usually erratic and associated with periodic drought. The climatic condition in Sokoto state explains the need for irrigation particularly for cereal and vegetable dominant farming system [1]. Rural farmers in Sokoto State, Nigeria produce Amaranthus for the fresh vegetable market on small irrigated lands. This is mostly because the cost of irrigation water, especially during dry season, is a major expense associated with vegetable production. Recent improvement of on-farm irrigation systems and the introduction of low-cost, water-saving irrigation technologies such as Partial root zone drying (PRD), have been identified as key and attainable components for reducing agriculture's water demand.

PRD is an irrigation strategy designed to increase water-use efficiency (WUE). This method limits vegetative shoot growth in favor of crop development with the goal that neither the current nor return yield is negatively affected. However, vegetative growth and development are limited by nitrogen availability more than any other nutritional factor. The absorption nitrate and ammonium by plants form numerous nitrogenous compounds which are mainly proteins that are essential to growth and metabolism [2] PRD is a variation of root deficit irrigation that generally improves the water use efficiency of crops [3,4,5]. Where other deficit strategies such as Regulated deficit irrigation (RDI) lead to negative outcomes, PRD offers the potential for use [6]. The proposed physiological mechanism of PRD is that roots in drying soil synthesize a hormonal signal (abscisic acid, ABA) which is transported to the shoots, indicating a developing soil water deficit. In the leaves, ABA induces partial stomata closure which increases WUE.

The pressure on water resources is expected to increase as the population grows which is the case in Nigeria. Improvements in irrigation management through introduction of low-cost, water saving irrigation technologies have been identified as a key and attainable component for reducing agricultures water demand, leaving more water for municipal water users, recreational users and environmental needs. PRD is a way of manipulating water use and crop growth without genetic manipulation. Significant benefits can be obtained without the use of high technology and so the technique can be of enormous benefit in agricultural systems of developing countries in Africa [7]. Using PRD technique is quite simple. It requires only the adaptation of irrigation systems to allow alternate wetting and drying part of the root-zone.

It was observed that potato production is best when the plant receives full irrigation. However, in areas where water is restricting production, PRD offers a good alternative [8]. The effects of PRD on a range of crops were investigated (including citrus fruits, olives, tomatoes and cotton) around the Mediterranean. UK trials are currently being conducted on raspberries. The latest results from Cukurova University in Turkey show that PRD can result in very significant savings in the use of water for the production of cotton [9]. Kirda and his team have shown that the PRD cotton crop produced its commercial yield several weeks earlier than the conventional crop, thereby increasing the chances of a high quality cotton yield before the autumn rainy season.

In the semi-arid region of Washington state, partial root-zone drying (PRD) of Fuji apples conserved 35% to 45% of irrigation water with minimal reduction in apple yield and size as compared to a control treatment [6]. Similarly, when PRD was applied for the final seven weeks prior to harvest, fruit size and yield of Golden Delicious apple grown near Prosser, Washington did not reduce while saving 50% of irrigation water over this same period [10]. PRD resulted in water savings and reduced crop evaporative consumption in two legumes in Uzbekistan. The reduction was greater in green gram than common bean [11]. Partial root drying with furrow or flood irrigation has been successful in experiments with citrus and pears in commercial vineyards in Australia [12]. The results of PRD on fruit composition in respect to wine-making attributes indicate that quality is at least maintained if not improved [13]. In Malaysia, tomato yield was also not significantly affected by PRD application [14].

Although PRD has been used successfully in root and tuber crops, vegetables and fruit-producing crops such as potatoes, tomatoes, grapes and oranges in Europe, Australia, North and South America, little is known about how leafy and fruit-producing vegetable crops grow in Africa, particularly in semi-arid environments in northern Nigeria where water resources are scarce and local farmers' income low. Thus, the main purpose of this research was to test the feasibility of using partial root zone drying (PRD) in Sokoto State to reduce the amount of water used in Amaranthus production and, thus, increase rural farmers' net income as well as ensure a sustainable environment.

Materials and Methods

Plant material: Experimental *Amaranthus candatus* seeds were planted in rows on 8cm ridge height to create two wetted zones per plant that could be alternately irrigated on a cycle of one week, i.e., while one zone was wetted, the other zone would be dried. The experiment was conducted on three plots (one for each treatment) with dimensions 289.56cm × 106.68cm. Each had seven rows and eight furrows. Organic manure was added to each ridge before planting and two weeks after planting (2WAP). Figure 1 showed the *Amaranthus* at 50% PRD and 100% CWR (denoted on the field by Normal Irrigation; NI).

Figure 1 Layout of 50% PRD and 100% CWR plots

Treatments and Environmental Conditions: Three treatments were compared. One had half of the root system watered and half droughted by delivering 50% less water per irrigation than the well-watered control (50%PRD). Another had both halves of the root system watered delivering 50% less water per irrigation than the control (50%CWR); and the third had both halves well-watered (100%CWR). The drying episode of 50%PRD treatment was initiated on 6th of May, 2009 (hereafter referred to as day 0) by withholding water from the second, fourth and sixth furrows of the plot (while other furrows were irrigated); the drying period continued for a week. The 50%CWR and 100%CWR plants were watered as needed throughout the experiment, about every day.

Water Status Measurements: The experiment was carried out in the dry season and hence needed total irrigation. Monthly mean maximum temperature data for Sokoto was used for determining the monthly crop water requirement (CWR). This was corrected for the duration of sunlight for the month and latitude. Daily need of the plant treatments were measured and supplied to the plots.

Experimental Design and Statistical Analysis: The experiment was designed to know the sensitivity and response of Amaranthus plants to non-hydraulic signals of partial soil drying. It was expected that all growth parameters will be significantly reduced in response to non-hydraulic signals of soil drying. Growth parameter measurements taken weekly from three weeks after planting (3WAP) to five weeks after planting (5WAP) were statistically compared. Charts were used to describe the effects of different water application rates on the growth parameters of treatments.

Results and Discussion

Water application rate versus average plant height and plant girth (3WAP to 5WAP). Water application rate of each treatment is expressed relative to the average of the stem heights and stem girths for that week in Figure 2. Drying reduced average plant heights of 50%PRD plants, after water was alternately withheld from a side furrow, and 50%CWR plants to 32% and 27.5% of 100%CWR plants (control) respectively by the third week after planting (3WAP). Average plant height of 50%PRD plants then remained inhibited about 4WAP while that of 50%CWR plants declined to 22.5% of control. At 5WAP, average plant heights of 50%PRD plants and 50%CWR plants increased to about 50% and 30% of control value respectively. Drying also reduced average plant girths of 50%PRD plants and 50%CWR plants to about 51% and 47% of 100%CWR plants (control) respectively by the third week after planting (3WAP). At 4WAP, average plant girth of 50%PRD plants increased to 57% of control while average plant girth of 50%CWR plants dropped to about 36% of control. Average plant girth of 50%PRD plants increased fairly rapidly, rising to 82% of control value for about the next week (5WAP), while that of 50%CWR plants also increased to 50% of control.

Water application rate versus number of leaves (3WAP to 5WAP): Number of leaves differed among treatments between 3WAP and 5WAP, Figure 3. In 50%PRD and 50%CWR plants, at 3WAP, the total number of leaves of the identified individuals within each treatment declined to about 68% and 22% of the control value respectively. At 4WAP, Figure 3 shows number of leaves significantly increased to 72% and 55% of control for 50%PRD and 50%CWR plants respectively. Number of leaves of 50%PRD plants rose to 84% of control while that of 50%CWR plants remained at 55% of control at 5WAP.
Plant height of each of the 21 identified plants in each treatment was measured from the top of the soil to the top of the main plant stem and the girth measured at 1cm from the top of the soil. Weekly averages were calculated and recorded as shown in figure 2. Weekly number of leaves of the twenty one identified plants of each of the three treatments was counted. Every visible leaf on the plants, including the tips of the ones just beginning to emerge, was counted (Figure 3). Measuring Wet Weights, removing a plant from the soil can cause trauma and affect the ongoing growth rate and thus the experiment. Measuring wet weights of plants was therefore saved as a final measure of growth at the end of the experiment at 5 weeks after planting (Figure 4). Plants were removed from the soil and any loose soil was washed off. Removal of any free surface moisture was done by blotting plants gently with soft towel. Plants were weighed immediately to avoid loss of moisture.

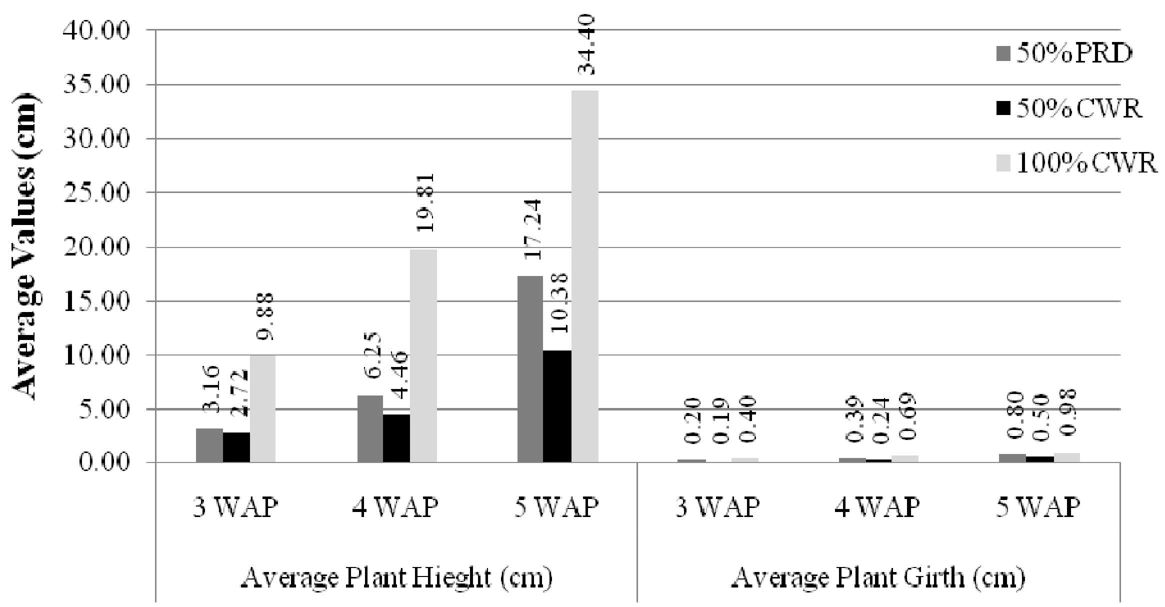

Figure 2: Effects of water application rate on average plant height and girth of the treatments (3WAP to 5WAP)

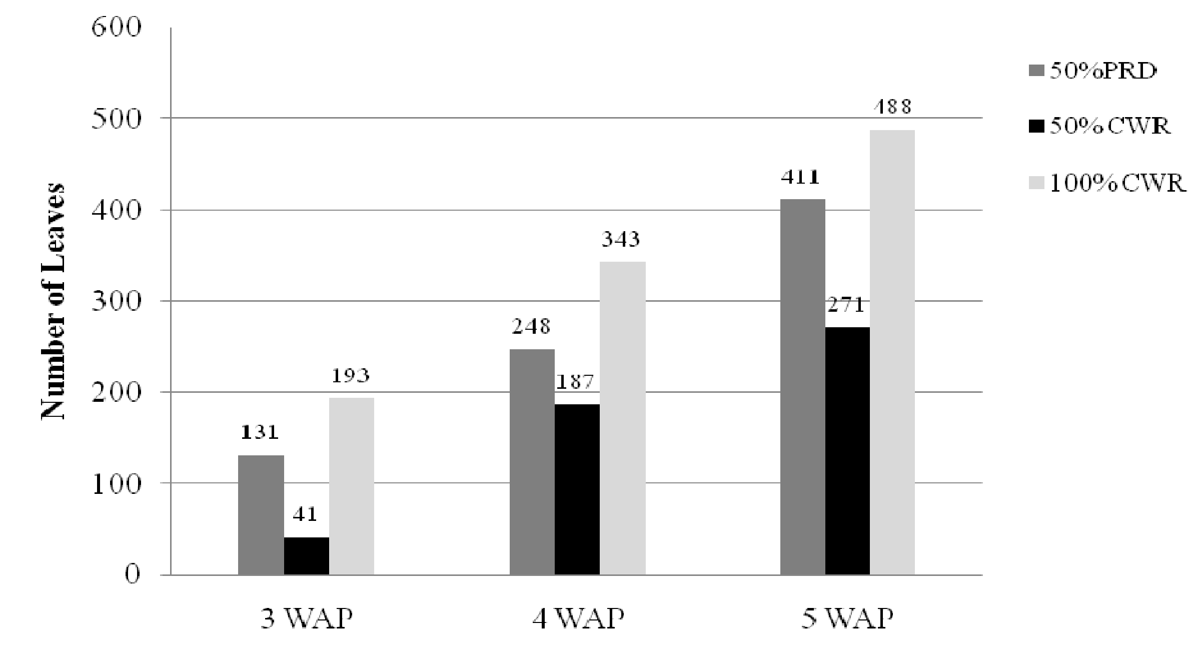

Figure 3: Effects of Water application rate on number of leaves of the treatments (3WAP to 5WAP)

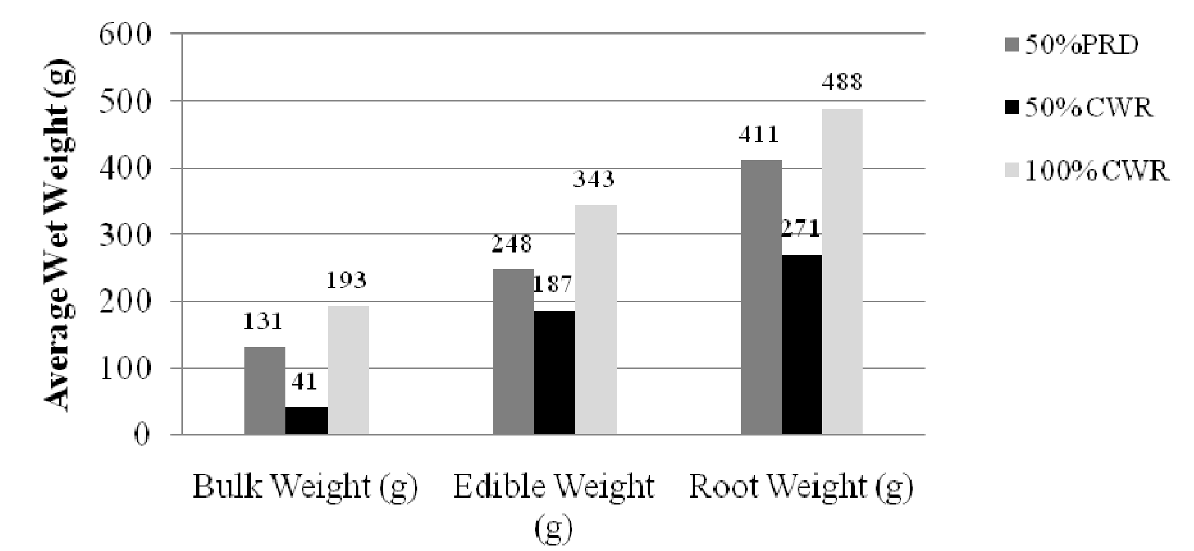

Figure 4: Effects of water application rate on average bulk, edible and root wet weights of the treatments (5WAP)

Bulk, edible and root wet weights (5WAP): Average bulk wet weights of the 50%PRD plants and 50%CWR plants five weeks after planting (5WAP) were about 63% and 19% of 100%CWR plants (control) respectively, Figure 4. Average edible wet weights of the 50%PRD plants and 50%CWR plants were 81% and 25% of control respectively. At plant level, partial drying stimulates root development, because Amaranthus roots are susceptible to water deficit in the soil. Hence, the average root wet weight of the 50%PRD plants is greater than that of 50%CWR plants - about 40% and 11% of control respectively.

Leaf Area: In 50%PRD and 50%CWR plants, there were reductions in vegetative growth as measured by average wet weights, Figure 4. Much of the reduction in biomass of the canopy was due to reduced leaf area. Total leaf area of 50%PRD plants was about 36% less than control while the area of leaves on 50%CWR plants was 78% less than control, Figure 5. Though, equal quantity of water (half of the control) was applied to these two treatments, the marked difference in their leaf area was as a result of the technique of irrigation used. 50%PRD plant root system, during partial drying, became bigger and longer than 50%CWR plant root system, developing more lateral roots while searching for moisture. Hence, larger area of leaves appeared to be linked to larger root systems. These results were quite similar to those observed with PRD tomato plants [14].

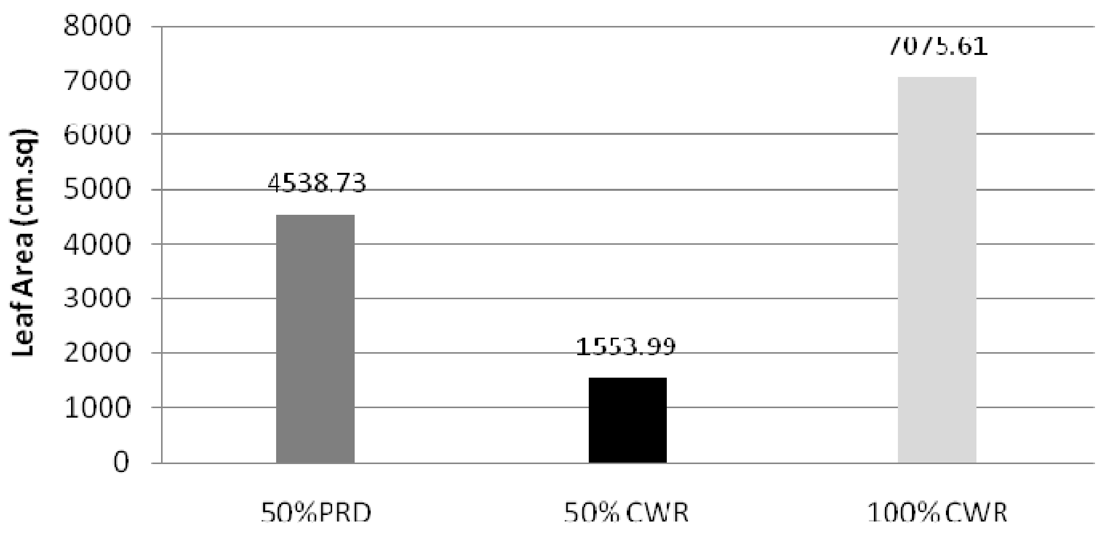

Figure 5: Effects of water application rate on leaf area of the treatment (5WAP)

Wet Root to Shoot Ratio: Roots allow plants to absorb nutrients and water from the surrounding soil and a healthy root system is vital to a healthy plant. The wet root-shoot ratio is one measure to help assess the overall health of plants. The control group of plants (100%CWR) provided a "normal" average wet root-shoot ratio for each of the plant treatments, any changes from this normal level (either up or down) was an indication of a change in the overall health of the plant. This was done after the plants were removed from the soil. Loose soil was washed off and any free surface moisture was blotted. Each plant root was separated from the top (cut at soil line) and both were weighed separately. The wet root-shoot ratio was calculated for each treatment (Table 1). A decrease in the ratio for 50%PRD treatment, compared to the other treatments, was an indication of healthier and more profitable plants because the decrease came from a greater shoot size.

Table 1 Average wet root-shoot ratio of Amaranthus

Treatment	Average wet root-shoot ratio
50%PRD	0.33
50%CWR	0.40
100%CWR (Control)	0.66

Conclusion

Partial root drying (PRD) uses biochemical responses of plants to water stress to achieve a balance between vegetative and reproductive development. By doing so, it achieves a secondary goal of significant improvement in production per unit of irrigation water applied. Even though the irrigation amount was halved, there was no significant reduction in yield due to 50%PRD treatment. This contrasts with 50%CWR treatment, where savings in irrigation application have been at the expense of yield.

These results are in agreement with many findings dealing with PRD [3,15]. The experiment has shown that if PRD is applied properly, there should be no significant yield reduction, although irrigation amount may be halved. A critical irrigation management practice with PRD is to ensure adequate rewetting of the dry side. Failure to ensure adequate replenishment of deep soil layers after switching sides may result in water stress, which may significantly reduce edible weight during the early stages of leaf development.

The cost of implementing PRD varies depending on the irrigation system employed. The additional outlay of using PRD is economical where the cost of irrigation water is high and as water becomes an increasingly valuable and scarce resource. The true environmental cost of irrigation water will always justify the cost of implementing PRD.

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