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RESEARCH ARTICLE

Effect of Different Irrigation Levels on Yield Attributes of Black Pepper (*Piper nigrum* L.)

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ABSTRACT

The growth of black pepper cultivations in Sri Lanka has been restricted to the Wet Zone of Sri Lanka due to lack of sufficient soil water in the Dry Zone as well as in certain parts of the Intermediate Zone. Therefore, identification of optimum irrigation level to get a higher yield of black pepper is vital as such information is limited. A pot experiment was conducted under protected environmental conditions to determine the effect of different irrigation levels on yield attributes of black pepper. Weekly irrigation was administered to three-year-old MB-12 vines at three different levels (8, 4, and 2 L vine^{-1} week^{-1}; 8 L vine^{-1} week^{-1} represents near field capacity) with 3 replicates each. The experiment design was Completely Randomized Design (CRD). Black pepper vines provided with an irrigation level of 8 L vine^{-1} week^{-1}, recorded significantly higher ($P<0.05$) mean values for yield attributes such as dry weight of berries of 10 spikes (40.5 g), spike length (11.76 cm), number of spikes per vine (81), number of berries per spike (87.4), and spike filling percentage (88.9%). In conclusion, irrigation level near field capacity (8 L vine-1) is preferable to get a greater yield from black pepper. Further studies are suggested at the field level before making a solid recommendation.

Keywords: *Black pepper, Moisture stress, Irrigation, Yield attributes*

INTRODUCTION

Black pepper (*Piper nigrum* L.) is one of the most widely used spices all around the world. It is one of the key export crops in Sri Lanka, which earns foreign exchange for the country (Senevirathna and De Silva, 2022). Pepper is grown mostly as a mixed crop and as a rain-fed crop in the Wet and Intermediate Zones of Sri Lanka. The ideal annual rainfall for pepper is about 2,000 mm with uniform distribution. Total rainfall and its distribution influence the productivity of black pepper. The crop suffers from soil moisture stress during dry spells leading to yield penalties. Black pepper plants are highly susceptible to water shortage and show low capability for recovery after stress (Ambrozim *et al.*, 2022). The black pepper annual cycle is broadly divided into; (1) lag period (March-May): its interval is between harvest and subsequent spike initiation; (2) spike emergence and flower bud differentiation (June-July): new leaf accompanied by spike; (3)

spike enlargement and berry formation (August-October); (4) berry development (November-December); and (5) maturity and harvest (January-February). These phases may overlap and vary depending on rainfall distribution, variety, and location (Krishnamurthy *et al.*, 2016).

Understanding the relationship between crops and weather is important to determine the yield of crops. Any change in local weather conditions mainly during critical developmental stages of the crop may adversely affect growth processes and lead to a huge reduction in yield (Bannayan *et al.*, 2011). According to Monteith (1981), the two main causes of yield variability are considerably higher changes in temperature and rainfall. Climate-related risks in agricultural production have been reported through various studies (Phillips *et al.*, 1999; Andresen *et al.*, 2001; Reilly 2002). Lobell *et al.* (2007) investigated the relationship between crop yield and climatic variables (precipitation and temperature) for major crops in California. They found that the effects of climatic variation differed among the crops studied and depended upon the crop growth stage when the variation occurred. Jayawardene *et al.* (2013) studied factors affecting smallholder black pepper production in the Kurunegala district of Sri Lanka. According to their results, precipitation levels were significantly associated with the productivity levels of black pepper.

Ambrozim *et al.* (2022) studied the physiological responses in young black pepper vines under different irrigation levels and their recovery capacity after a water deficit. They have found a reduction in stomatal conductance, leaf osmotic potential and relative water content of the water-stressed black pepper plants. Pillay *et al.* (1988) compared rainfall patterns and the black pepper yields during two extremely adverse years (1980-1981 and 1986-1987) with that of a favourable year (1981-1982) and noted a 75% yield reduction in both adverse time periods due to distinct breaks in the rainfall during the critical period of flower initiation. On contrary, pepper yield was high in the favourable year (1981–1982) where precipitation remained steady without any break. They also observed that a low rainfall (70 mm in 20 d during May) is enough to initiate the flushing and flowering process. The change in rainfall pattern during 1999–2000 crop season affected the flowering and yield of black pepper in Idukki, India a predominant black pepper-growing zone (John *et al.*, 1999). A similar observation was also noted in Bangka, Indonesia, by Suparman (1998). A period of dry spell before reproductive primordial initiation helps in inducing profuse flowering. Flowering to fruit ripening is the most sensitive period for moisture stress in black pepper (Kandiannan *et al.*, 2014). Within this critical period of 16 weeks, if any dry period occurs, it can result in reduced yield (Pillay *et al.*, 1988). Thus, maintaining soil moisture regime at an optimum level is very important for black pepper.

Today, environmental conditions are so unpredictable due to the impacts of climate change and global warming. Recent studies using general circulation models predict an elevated temperature by the year 2050 in all regions of Sri

Lanka which would then induce a high soil moisture deficit (De Silva *et al*., 2007). Moisture stress is the most limiting factor, which causes variations in the yield of many crops, being frequently related to changes in cell volumes, and as a consequence with the loss of turgor, interruption of water potential gradients and limitations to the diffusion of gases (Kavroulakis *et al*., 2018). Such variations can be observed in pepper vines but limited scientific evidence is available in the Sri Lankan context. These variations may affect both the quantity and quality of the yield. To understand the variation of different yield parameters under moisture stress conditions, a proper scientific investigation should be carried out under different moisture regimes by providing pepper vines with different irrigation levels.

The present study was thus conducted with the objective of identifying the variation of different yield attributes of black pepper under different irrigation levels.

MATERIALS AND METHODS

A pot experiment was carried out using uniform, 3-year-old 27 black pepper vines inside a shade house according to Completely Randomized Design (CRD). Three irrigation levels (8, 4, 2 L vine^{-1} week^{-1}; 8 L vine^{-1} week^{-1} represents the field capacity) were applied weekly as the treatments to the selected black pepper vines of 3 replicates (Each replicate consisted of three black pepper vines). They were grown in 38.7 L pots filled with a potting mixture of Reddish-Brown Latosol (an Oxisol) and compost at a 2:1 ratio. The field capacity of the potting mixture was determined using the field method and the value was 17.4% VWC (volumetric water content). Treatments were decided based on the fact that none of these treatments will reach the field capacity level after irrigation in order to minimize the amount of water usage due to water scarcity in the Dry Zone (average VWC was 15.7%, 10.4% and 8.7% when applied 8 L, 4 L, and 2 L, respectively).

Different yield parameters such as total number of spikes per vine, spike length, spike filling percentage, number of berries per spike, and dry weight of berries of 10 spikes were recorded after six months. Data were subjected to Analysis of Variance (ANOVA) with MINITAB 17 software (https://www.minitab.com/en-us/products/minitab/). Treatment means were compared using the Tukey test at $P<0.05$ probability.

RESULTS AND DISCUSSION

Moisture stress affects plant water relations through the reduction of leaf water content and water potential leading to reduced turgor. It also affects the stomatal conductance and limits gaseous exchange in addition to reducing transpiration and arresting photosynthesis rates (Razak *et al*., 2013). Decreased leaf growth, total leaf area and leaf-area plasticity were observed under drought conditions in many plant species, such as peanut and Oryza sativa (Lisar *et al.*, 2012). Although water saving is an important outcome of lower leaf area, it leads to a decrease in carbon assimilation (Lisar *et al.*, 2012). Drought stress causes various physiological and biochemical changes in black pepper too (Krishnamurthy *et al.*, 2000). These physiological impacts that happen due to water stress, ultimately reduce the crop yield attributes and total yield in crops. It is evident through the results obtained in the current study also as the yield parameters such as total number of spikes per vine, spike length, and spike filling percentage progressively decreased with decreasing levels of irrigation.

Total number of spikes

The total number of spikes initiated in a vine was significantly ($P<0.05$) different among treatments (Table 1). Black pepper vines, which were provided with 8 L of water vine^{-1} week^{-1}, showed the highest mean value of the total number of spike initiations (81) and it was 84.1% higher than that of the 4 L per plant treatment and 125% than that of the 2 L per plant treatment.

Table 1: Effect of different irrigation levels (8, 4 and 2 L plant^{-1} week^{-1}) on total number of spikes per vine, number of berries per spike, and dry weight of berries of 10 spikes in a vine. Means that do not share the same letter are significantly different at a 0.05 probability level.

Irrigation level (L per plant per week)	Total number of spikes per vine	Number of berries per spike	Dry weight of berries of 10 spikes (g)
8	81 ± 7.42a	87.4 ± 5.13a	40.5 ± 3.68a
4	44 ± 2.42b	21.7 ± 2.13b	25.4 ± 1.88b
2	36 ± 5.34b	17.9 ± 2.75b	17.4 ± 1.23c
P value	0.001	0.001	0.001

In this study, the pots that received 8 L of water vine-1 week-1 were closer to the field capacity (90% of FC) and showed better results. As per the study conducted by Ankegowda *et al.* (2011), the number of spikes per m^2 was significantly greater in irrigated vines compared to rain-fed vines of black pepper. Previous studies conducted on various other crops have also reported better performances when irrigated up to the field capacity than other levels of water application particularly under stress conditions (Al-Naeem, 2008). According to Zhang *et al.* (2006), the yield of wheat under minimum irrigation has reduced as a result of less spikes per area and a lower grain number per spike. In their study, in eight seasons, the spike density and the kernel numbers per spike are, on average, 12 and 7.8% lower in minimum irrigation than in full irrigation treatments, respectively (Zhang *et al.*, 2006). In our study, black pepper also showed a significant ($P<0.05$) decrease in total number of spikes with the decrease in irrigation level.

Water stress can lead to disturbed nutrient uptake efficiency and photosynthetic translocation within the plants (Iqbal *et al*., 1999). For example, according to Nawaz et al. (2012), the uptake of nitrogen (N) in wheat plants has decreased by 38 and 46% under early and late drought stress, respectively. Further, the maximum intake of N (115.2 mg) in crop plants resulted by the normal water supply (control) and the minimum intake of N (62.45 mg) was shown by the plants that were under stress for six weeks after emergence (Nawaz *et al*., 2012). Commonly, a reduction in the number of spikes is a symptom of N deficiency that can happen due to a reduction in N uptake by a plant (Armitage and Larson, 1992). Therefore, it is possible that the moisture stress condition may have interfered with N uptake and in turn, photosynthetic translocation in black pepper plants reducing the total number of spikes ultimately.

Number of berries per spike

There was a significant ($P<0.05$) difference in mean number of berries per spike among the treatments (Table 1). The lowest mean number of berries per spike was observed in the 2 L vine-1 treatment whereas the highest mean number of berries per spike was observed in the black pepper vines provided with 8 L vine-1 week-1 which was 388.3% higher than that of the 2 L per vine-1 treatment. However, no significant ($P>0.05$) difference could be observed between the 2 and 4 L vine-1 treatments (Table 1).

Similar results were obtained in previous studies conducted for various crops including black pepper. As per the study conducted by Ankegowda *et al*. (2011), the number of berries per spike was doubled in irrigated vines compared to rain-fed vines of black pepper. Dencic *et al*. (2000) have found that water stress results in a decrease in number of grains per spike in 30 wheat cultivars evaluated from different countries. According to Maqsood and Azam Ali (2007), in a similar study, it is reported that water stress reduces the number of seeds per ear in millet. In the present study, the reason for black pepper vines, which received low irrigation levels to have a lesser number of berries per spike than the 8 L per plant treatment, might be due to the fact that black pepper vines are sensitive to water stress.

Dry weight of berries

There was a significant ($P<0.05$) difference in mean dry weight of berries among the treatments (Table 1). Black pepper vines provided with 8 L vine-1 week-1 showed the highest mean dry weight of berries of 10 spikes of a vine. It was 57% higher than the lowest mean dry weight of berries, which was shown by vines provided with 2 L of water vine-1 week-1.

The results of this study can be related to the findings of previous studies. It was found that water shortage, particularly during the rapid fruit expansion stage (a critical period), often reduces the growth of the coffee berries (Dancer, 1964; Cannell, 1971; 1974; Miguel *et al*., 1976), as the ovules do not reach their full size under limited water levels (Cannell, 1974). When the rate of photosynthesis is reduced as a result of a reduced amount of water, the sensitive phytochrome pigments (chlorophyll pigmentation) that intercept light for the process are affected; then, the plants subjected to water stress are expected to have small and light fruit weights (Pill and Lambeth, 1980). In our study too, black pepper vines provided with lower irrigation levels, resulted in berries with lesser fresh weights, compared to 8 L vine^{-1} week^{-1} treatment.

Pepper leaves photosynthesize more efficiently when water is abundant, leading to a higher percentage of large, heavy, marketable fruits (Alvino et al., 1994). Under drought stress, the products of photosynthesis are fewer; fruit growth and development are inhibited, and yield is reduced (Bray, 1997). Furthermore, chlorophyll destruction is quickened by moisture stress (Alberte *et al*., 1997). A study on Cocoa donr by Carr and Lockwood (2011) found that, during the development of small fruits of Cocoa (known as cherelles), it may stop the growth (known as 'cherelle wilt') at certain points under water stress conditions. In this respect, water stress has an indirect impact on the 'wilting' process of Cocoa as carbohydrate assimilation is reduced (Carr and Lockwood, 2011). Therefore, such impacts on pepper berries might be the cause for berries of black pepper vines which received lesser irrigation levels to have lesser dry weights than the berries of vines which received 8 L vine^{-1} week^{-1}.

Spike length

There was a significant ($P<0.05$) difference in mean spike length among treatments as evident in Figure 1. Black pepper vines, which were provided with 8 L vine^{-1} week^{-1}, showed the highest mean spike length (11.76 cm) and it is 120.6% higher than the lowest mean spike length (5.33 cm) which was observed in 2 L vine^{-1} week^{-1} treatment.

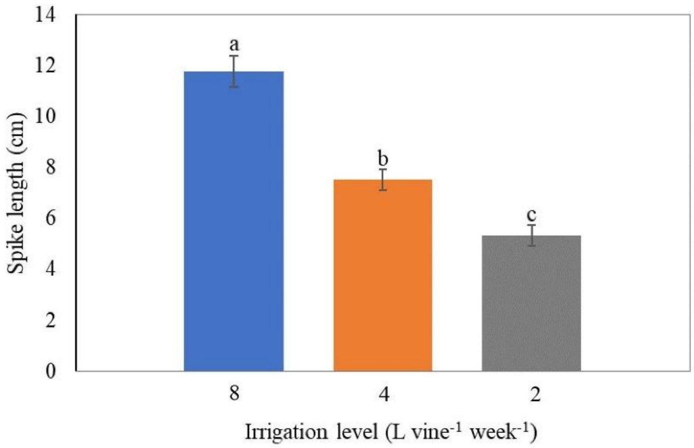

Figure 1: Variation of spike length of black pepper under different irrigation levels (8, 4 and 2 L vine^{-1} week^{-1}). Means that do not share a same letter are significantly different at P = 0.05 probability level.

The results obtained in this study, suggest that black pepper vines, which received the irrigation treatment near field capacity, resulted in longest spikes (Figure 1). It was found that the application of water stress to wheat (Mirbahar *et al*., 2009) and barley (Al-Naeem, 2008) plants negatively affects all the yield parameters including spike length and thus the final grain yield.

Impaired water supply during both phenophases (vegetative phase and reproductive phase) reduced the leaf area index and thus the growth of the barley and rice crops due to a decrease in turgor pressure as a result of less available moisture (Ajaykumar and Krishnasamy, 2019; Khalvati *et al*., 2005). Reduction in leaf area index, which limits assimilate supply, may lead to a reduction in yield parameters such as spike length. Furthermore, cell elongation has been reported to be lower under low turgor pressure resulting from water stress (Jürgen 1997). Such impacts may be the underlying reason for the reduced spike length of black pepper reported under the lower irrigation level of the present study.

Spike filling percentage

Different irrigation levels had a significant effect (P<0.05) on the mean spike filling percentage (Figure 2). Black pepper vines, which were provided with 8 L vine-1 week-1, showed the highest mean spike-filling percentage (88.9%). The lowest mean spike filling percentage (55%) was observed in 2 L vine^{-1} week^{-1} treatment which is 38.1% lower, compared to 8 L vine^{-1} week^{-1} treatment. Nevertheless, there was no significant (P>0.05) difference between 4 and 2 L vine^{-1} week^{-1} treatments (Figure 2).

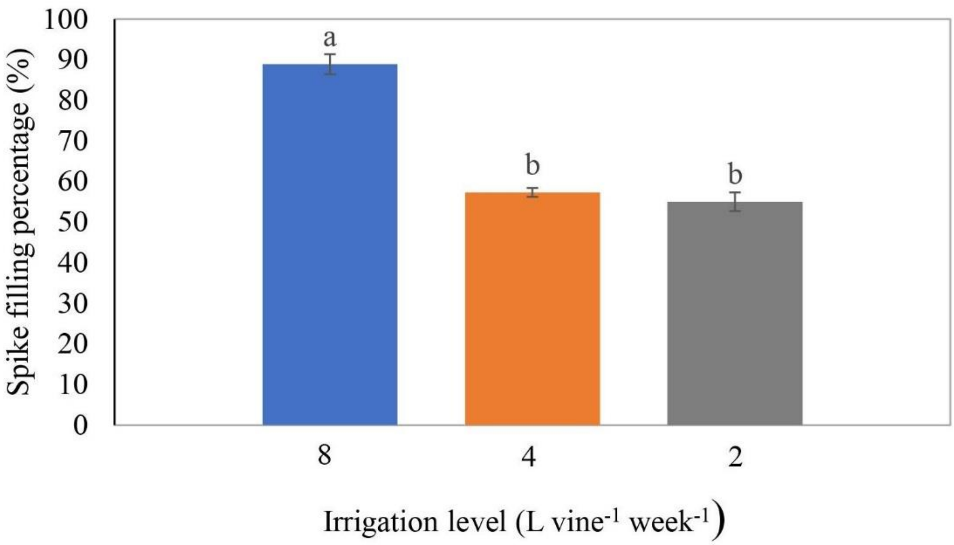

Figure 2: Variation of spike filling percentage (%) under different irrigation levels (8, 4 and 2 L vine^{-1} week^{-1}). Means that do not share a same letter are significantly different at P = 0.05 probability level.

In this study, black pepper vines which received the treatments 4 and 2 L per vine^{-1} week^{-1} had lesser spike filling percentages, compared to 8 L vine^{-1} week^{-1}. Pradhan *et al*. (2012) state that the most sensitive phases of wheat to water stress are reproductive and grain-filling phases although moisture stress may impact on the growth during all phenological stages. In another study on grain crops, it was concluded that water scarcity during early grain development curtails potential grain size by reducing the rate and duration of grain filling (Saini and Westgate, 2000). This may apply to the observed variation in spike-filling percentages of black pepper in this study.

Pre-anthesis assimilates contribute to grain filing in both well-watered and stressed crops. Remobilization of these assimilates compensates partly for the decline in photosynthesis during grain filling in stressed plants, resulting in low grain filling percentages (Fereres and Dugo, 2009). In the present study too, the observed differences among the treatments may be due to the same reason; the black pepper plants, which received lesser irrigation treatments, have resulted in lesser spike filling percentages (Figure 2).

CONCLUSIONS

All yield attributes were significantly higher in black pepper vines applied with the irrigation level near field capacity (8 L plant-1 week-1). Most of the yield attributes had been progressively decreased with decreasing levels of irrigation. Therefore, an irrigation treatment near field capacity (17.4% VWC) will be more suitable to get a higher yield in black pepper vines aged around 3 years. Further studies are suggested at the field level before making a solid recommendation.

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