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Soil water stress ranges: water use efficiency and Chinese cabbage production in protected cultivation

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ABSTRACT

Water deficit or water excess can affect development and yield of vegetables. The objective of this study was to evaluate the effect of different soil water stress ranges for Chinese cabbage (*Brassica pekinensis*) in a protected cultivation. The researches were carried out at the Olericulture Sector of Universidade Federal Tecnologica do Paraná between April and July, 2015 and January and April, 2016. Two Chinese cabbage cultivars were analyzed (Eikoo and Kinjitsu) with four soil water stress range (13-17, 23-27, 33-37 and 43-47 kPa) moments of irrigation indicative parameters. The trial design was completely randomized, with four replications, in a factorial scheme. For head fresh mass, a soil stress range of 13-17 kPa resulted in higher yield (527.2 g/plant), in the first research. In the second one, 'Eikoo' showed higher productivity in the stress range 13-17 kPa (70.7 t ha^{-1}). About water use efficiency, higher values were obtained, 42.1 kg m^{-3} in the first research and 47.3 kg m^{-3} in the second one with Kinjitsu and Eikoo cultivars, respectively, in the stress range 13-17 kPa. 'Eikoo' had a higher productivity than 'Kinjitsu' in the second research (summer), but in the first one (autumn-winter) these differences were not expressive. The use of stress ranges as indicative of irrigation return time between 13-17 kPa is suitable for Chinese cabbage crop.

Keywords: *Brassica pekinensis*, tensiometry, irrigation management, water deficit.

RESUMO

Faixas de tensão de água no solo: eficiência do uso da água e produção de couve chinesa em cultivo protegido

O déficit hídrico ou excesso de água pode afetar o desenvolvimento e produção das hortaliças. Objetivou-se avaliar o efeito de diferentes faixas de tensão de água no solo para a cultura da couve chinesa (*Brassica pekinensis*), em ambiente protegido. Os experimentos foram conduzidos no Setor de Olericultura, da Universidade Tecnológica Federal do Paraná entre abril e julho de 2015 e janeiro e abril de 2016. Foram estudadas duas cultivares de couve chinesa (Eikoo e Kinjitsu) e quatro faixas de tensão de água no solo (13-17, 23-27, 33-37 e 43-47 kPa), sendo parâmetros indicativos do momento de irrigar. O delineamento experimental utilizado foi inteiramente casualizado, com quatro repetições, em esquema fatorial. Para massa fresca da cabeça, a faixa de tensão do solo de 13-17 kPa resultou em maior produção (527,2 g/planta), no primeiro experimento. No segundo, 'Eikoo' apresentou maior produtividade na faixa de tensão 13-17 kPa (70,7 t ha^{-1}). Quanto à eficiência no uso da água, foram obtidos maiores valores, da ordem de 42,1 kg m^{-3} água no primeiro e 47,3 kg m^{-3} água no segundo experimento, para as cultivares Kinjitsu e Eikoo, respectivamente, na faixa de tensão 13-17 kPa. 'Eikoo' teve maior produtividade do que a 'Kinjitsu' no segundo experimento (verão), porém no primeiro experimento (outono-inverno) essas diferenças não foram expressivas. A utilização de faixas de tensão como indicativo do momento de retorno à irrigação entre 13-17 kPa é adequada para a cultura da couve chinesa.

Palavras-chave: *Brassica pekinensis*, tensiometria, manejo da irrigação, déficit hídrico.

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Chinese cabbage (*Brassica pekinensis*) is considered the world's most important vegetable from Brassicaceae family when it comes to global consume, because it is a key element for diets in many Asian countries. Due to its wide acceptance and high nutritional value, as a source of vitamin C, minerals such as sodium, potassium, magnesium and calcium, there is a constant request for this vegetable (Laczi *et al*., 2016).

Understanding soil moisture is of underlying importance, as it indicates its water status. In irrigation, this should be determined and will serve as a parameter for the amount of water to be applied by the irrigation system. There are several methods for determining soil moisture, which differ mainly by measurement means, measurement site, installation, cost, response time and ease of field operation (Mantovani *et al.*, 2009).

One of the most commonly used methods for indirect determination of soil moisture is the tensiometry, which uses sensors called tensiometers (Bernardo *et al*., 2006). Thompson *et al*. (2002) recommend, for broccoli and cauliflower, species of Brassicaceae, tensions between 10 and 12 kPa. Marouelli (2008) recommends the use of tensiometers in vegetable crops and leafy vegetables in general, and to keep tension between 10-20 kPa, seeking the lowest value for critical moments during its development.

Generally, vegetables show an underdeveloped root system, high water content in their constitution and a short cycle, so the occurrence of water deficit can severely compromise the farming (Marouelli, 2008). Thus, the great majority of vegetable crops in Brazil is conducted with irrigation, but an inadequate management can compromise the profitability and sustainability of production by excessive or poor water application (Beshir, 2017).

Having this in mind, the relevance of studies on hydric relations between crop, soil, environment and the minimum amount required for production maximization can be noted. There is a shortage of studies on irrigation management in Chinese cabbage. Therefore, the objective of this study was to evaluate the effect of different soil water stress ranges for Chinese cabbage in a protected environment.

MATERIAL AND METHODS

The research was carried out at Olericulture Sector of Universidade Federal Tecnologica do Paraná, Campus Dois Vizinhos (25º42'S, 53º06'W, altitude 520 m). Two researches were carried out, one from April to July 2015 and another from January to April 2016. The researches were conducted in a protected environment, arched model, covered with clear polyethylene, 150 µ thickness. The region climate is Cfa, according to Köppen classification (Alvares *et al*., 2013).

The trial design was completely randomized in a 2x4 factorial scheme, two cultivars (Eikoo and Kinjitsu) and four soil water stress ranges (13-17, 23-27, 33-37 and 43-47 kPa), with four repetitions. In each 18 L vase, a plant was managed, being considered an experimental unit, spaced 30 cm between plants and 60 cm between rows.

The soil used to fill the vases is classified as Dystroferric Red Latosol (Embrapa, 2018), taken from a 0-20 cm layer, dried, unstuck and sieved in a 3 mm mesh. These were the chemical characteristics of the soil: 5.8 pH ($CaCl_2$); 1.88% organic matter; 11.78 P (mg dm^{-3}); 76.32% V ; K, Ca, Mg, Al, H+Al, SB ($cmol_c\ dm^{-3}$) of 0.45; 6.10; 3.70; 0.00; 3.18 and 10.25, respectively. The soil was characterized as very clayey with 78.3; 16.7 and 5.0% clay, silt and sand, respectively. Its microporosity, macroporosity and total porosity were respectively 0.42; 0.31 and 0.73%; particle density 3.52 g cm^{-3}; soil density 0.95 g cm^{-3}. Soil water retention curve was determined in the Physics and Soil Water Laboratory of the Universidade de Passo Fundo, from undisturbed samples, collected at 0.10 m depth, with six repetitions (Figure 1). To determine the volumetric humidity of the low stress points (6 and 10 kPa) porous plate funnels were used; for 100 and 300 kPa stress the Richards chamber and pedotransfer functions (Michelon *et al.*, 2010) were used, to determine the humidity at 1500 kPa. The relationship between stress and volumetric moisture was adjusted using the model proposed by Van Genuchten (1980), described in equation (1):

$$\theta = \theta_r + \left(\frac{\theta_s - \theta_r}{[1 + (\alpha\ |\Psi m|)^n]^m}\right) \quad (1)$$

Where θ= volume-based soil moisture (m^3/m^3); Ψm= soil matrix potential (kPa); θ_r= residual volumetric moisture (m^3/m^3); θ_s= volumetric humidity at saturation (m^3/m^3); m, n and α= model parameters.

The m was obtained by equation (2) (Mualem, 1976):

$$m = 1 - \left(\frac{1}{n}\right) \quad (2)$$

In order to adjust the model, the RETC software was used (Van Genuchten *et al.,* 1991). The values of the adjustment parameters were depth = 0.10 m; residual volumetric moisture (m^3/m^3) = 0.078; volumetric humidity at saturation (m^3/m^3) = 0.43; m = 0.359; n= 1.56; α= 0.036 and R^2= 0.95.

Seedlings were produced in a tray of expanded polystyrene with 128 cells, filled with commercial substrate Tecnomax®. Vases were filled with soil and plantlets were transplanted with four to six leaves (Segovia *et al.*, 2000), 17 days after sowing date, in both researches. In the 2015 research, transplant was performed on May 6, 2015 and harvest on July 15, 88 days after planting date (DAS), using as indication of harvest point the sturdy head (Segovia *et al*., 2000). In the second research, transplant was performed on February 1, 2016 and harvest on April 10 (87 DAS), done in advance due to diseases incidence.

Up to the tenth day after transplant, irrigation was homogeneous, to guarantee the glue. Afterwards, started the discrimination of cultivations. Irrigation management was performed based on soil matrix potential, determined by tensiometers. The irrigation liquid level was applied manually using a graduated cylinder, aiming to evenly distribute the water all over the vase. A tensiometer was installed at 10 cm depth per experimental unit, according to procedures indicated by Marouelli (2008). Stress readings were performed daily at the end of afternoon, using a digital tensiometer. When the mean stress reached the cultivation stress range, irrigation was performed until reaching the field capacity (CC). For the soil water stress ranges (kPa) 13-17; 23-27; 33-37 and 43-47, at the time of irrigation, the irrigation levels per application (L) were 0.22; 0.65; 1.02 and 1.32, respectively. Soil moisture corresponding to the observed/measured stress was determined by means of the water retention curve (Equation 2), considering the depth of root system (100 mm), vase area (0.07 m^2) and mean value of the stress range humidity (θ_{atual}). Thus, the replacement volume was calculated (LLI) to reach the CC (0.397 $m^3\ m^{-3}$), according to equation (3) (Mantovani *et al.*, 2009).

$$LLI = (\theta_{cc} - \theta_{atual}).Z.PAM \quad (3)$$

Where LLI= irrigation liquid sheet (mm); θ_{cc}= field humidity capacity (m^3/m^3); $\theta_{current}$= current humidity (m^3/m^3); Z= root system depth (mm); PAM= vase area (m^2).

The mean temperature provided by climatic data, relative humidity and radiation were obtained from the UTFPR meteorological station (16 UTC) at Campus Dois Vizinhos, located nearby the experimental unit. Potential evapotranspiration was estimated by the Penman-Monteith method (Allen *et al.*, 1998).

Cultural practices, pest and disease

control were carried out according to the recommendations of Segovia *et al.* (2000). Fertilization was calculated based on soil chemical characteristics laboratory report and on recommendation proposed by Segovia *et al.* (2000). The urea fertilization was divided into three 40 kg ha^{-1} applications, in the planting, 15 and 30 days after the transplant; while phosphorus and potassium were applied in 100 kg ha^{-1} doses of P_2O_5 and 40 kg ha^{-1} of K_2O, in one single application, when preparing the soil in the vases. Same fertilization was used in both researches.

During harvest, the head circumference was measured with a tape measure, with results expressed in cm. To evaluate the compactness, grades from 0 to 5 were assigned, with 0 for plants with total head absence; 1 for plants with head without a defined core; 2 for plants with outside core head and loose peripheral leaves; 3 for plants with defined core head and leaves with inceptive compaction in the periphery; 4 for plants with defined core head and compact peripheral leaves, but with allowed visual individualization; and 5 for head with compact core and without visual individualization of the peripheral leaves (Souza *et al*., 2013).

To evaluate fresh mass, the aerial part was separated from the roots and weighed in a precision digital scale. Then, samples were taken to the drying oven at 65°C until constant mass.

Based on the considered spacing, population per hectare was estimated and multiplied by fresh mass of the head, estimating total productivity. Water use efficiency was calculated according to the productivity (dry mass of the head) and to the amount of water consumed by the crop in each cultivation during the cycle (Doorenbos & Kassan, 1994).

Otained data were submitted to analysis of variance (F test) and the cultivation effects obtained by means of Scott-Knott's test ($p<0.05$). Statistical analyzes were performed using GENES statistical software (Cruz, 2006).

RESULTS AND DISCUSSION

Mean temperature during the period of the research was 16.5°C in the first research and 21.8°C in the second one. This difference is attributed to the period when the researches were performed. The first research was carried out in autumn-winter period and the second one in summer-autumn period. Temperature conditions were suitable for the crop, considering that the majority of Chinese cabbage cultivars, including those used in this research, are adapted to temperatures between 15 and 25°C (Brasil, 2010).

There was no significant interaction between cultivars and soil water stress ranges for all analyzed traits in the first research. In the second one, there was a significant interaction, only for fresh and head dry mass, productivity and root dry mass.

Cultivars Eikoo and Kinjitsu did not differ significantly in the first research. However, in the second one, from 'Eikoo' a greater head fresh mass was obtained comparing to the 'Kinjitsu' (Table 1). Productivity was similar to head fresh mass, in which cultivar Eikoo produced 57.2 t ha^{-1}, while 'Kinjitsu' produced 30.2 t ha^{-1}. This response is conditioned to the cultivar characteristics, and 'Eikoo' can produce heads weighing 2.5-3.5 kg on average (Horticeres, 2015), while 'Kinjitsu' has a 2.2 kg mean head mass (Topseed, 2015). Based on this result, it can be suggested that the two cultivars can be conducted in the autumn-winter period, but 'Eikoo' can also be cultivated during summer period.

Table 1. Head fresh mass (HFM) and productivity of the Chinese cabbage submitted to different ranges of soil water stress in two crops. Dois Vizinhos, UTFPR, 2016.

Soil water tension (KPa)	HFM (g/plant)					
	2015			2016		
	Cv. Eikoo	Cv. Kinjitsu	Mean	Cv. Eikoo	Cv. Kinjitsu	Mean
13-17	463.0	591.3	527.2 a*	1272.5 Aa	517.3 Ba	894.9
23-27	441.5	458.0	449.8 b	1156.3 Aa	592.8 Ba	874.6
33-37	463.5	428.8	446.1 b	892.0 Ab	595.6 Ba	743.8
43-47	438.0	440.0	439.0 b	800.0 Ab	562.0 Ba	681.0
Mean	471.6	479.5^{ns}	-	1030.2	567.0	-
CV (%)	10.9		-	16.0		-
	Productivity (t ha^{-1})					
13-17	25.7	32.8	29.3 a*	70.7Aa	28.7Ba	49.7
23-27	24.5	25.4	24.9 b	64.2Aa	32.9Ba	48.6
33-37	25.8	23.8	24.8 b	49.6Ab	33.4Ba	41.5
43-47	24.3	27.8	26.1 b	44.2Ab	25.6Ba	34.9
Mean	25.1	27.5^{ns}	-	57.2	30.2	-
CV (%)	10.9		-	16.04		-

^{ns} not significant by Scott-Knott test ($p>0,05$). *Means followed by same capital letters in the row and lowercase in the column do not differ statistically by Scott-Knott test ($p>0,05$).

In a study by Seabra *et al.* (2014), evaluating the performance of seven Chinese cabbage cultivars in Cáceres-MT, under tropical climate, with average temperatures of 27.1ºC, the authors obtained head fresh mass ranging from 584 to 926.3 g/plant, 'Kinjitsu' presenting 883.3 g/plant, higher than that obtained in our two researches, 479.5 and 567.0 g/plant, respectively. On the other hand, head fresh mass obtained by these authors with 'Eikoo' (800.5 g/plant) was lower than that obtained in this study (1030 g/plant). Increased productivity (60.9 t ha^{-1}) achieved by Seabra *et al.* (2014) was lower than the highest obtained in this study (70.7 t ha^{-1}) with 'Eikoo', in the stress range of 13-17 kPa, using Dystroferric Red Latosol soil (Embrapa, 2006) with a very clayey texture. Possibly the milder temperatures (21.8°C) in the city of Cáceres-MT favored the increased productivity.

Regarding soil water stress ranges, in the first research, the best range was 13-17 kPa, differing from the others, which did not differ from each other. In the second research, 'Kinjitsu' was not influenced by the stress ranges. On the other hand, 'Eikoo' presented fresh mass in the upper head in the stress ranges of 13-17 and 23-27 kPa, with 1272.5 and 1156.3 g/plant, respectively, differing from the 33-37 and 43-47 kPa ranges, with 892 and 800 g/plant, respectively (Table 1).

Table 2. Head dry mass (HDM) and root dry mass (RDM) of Chinese cabbage plants submitted to different ranges of soil water stress in two researches. Dois Vizinhos, UTFPR, 2016.

Soil water tension (KPa)	HDM (g/plant)					
	2015			2016		
	Cv. Eikoo	Cv. Kinjitsu	Mean	Cv. Eikoo	Cv. Kinjitsu	Mean
13-17	30.0	30.0	30.0^{ns}	87.3 Aa*	39.3 Ba	63.3
23-27	27.5	33.0	30.3	91.5 Aa	40.5 Ba	66.0
33-37	28.0	27.5	27.7	38.8 Ab	36.8 Aa	37.8
43-47	30.0	31.0	30.5	31.4 Ab	41.5 Aa	36.5
Mean	28.9	30.4^{ns}	-	62.3	39.5	-
CV (%)	17.0		-	23.9		-
	RDM (g/plant)					
13-17	17.0	13.0	15^{ns}	25.0 Ab	20.3 Ba	22.7
23-27	17.0	15.0	16.0	28.3 Ab	20.8 Ba	24.6
33-37	15.0	13.1	14.0	38.0 Aa	19.5 Ba	28.8
43-47	14.0	13.0	13.6	40.0 Aa	21.0 Ba	30.5
Mean	15.8	13.6^{ns}	-	32.8	20.4	-
CV (%)	17.9		-	24.1		-

^{ns} not significant by Scott-Knott test (p>0.05); *Means followed by same capital letters in rows and lowercase in columns do not differ statistically by Scott-Knott test (p>0.05).

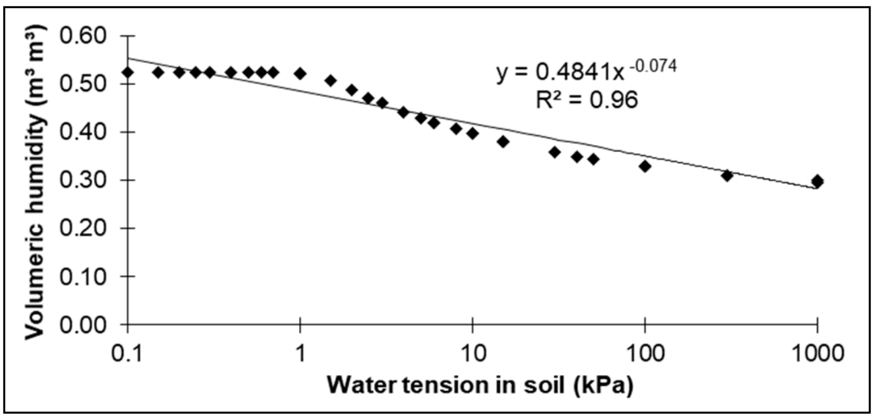

Figure 1. Soil water retention curve 0.10 m depth. Dois Vizinhos, UTFPR, 2016.

Soil water stress ranges are related to the additional energy expenditure that the plant makes to absorb water and use it in its vital processes, when water availability is reduced by the potential matrix reduction (Floss, 2011). Thus, the energy of the photoassimilates resulting from the photosynthesis process may have been primarily intended for water absorption, to the detriment of crop growth.

For Brassicaceae species, such as broccoli and cauliflower, stresses between 10 and 12 kPa are suggested (Thompson *et al.*, 2002). Likewise, Marouelli (2008) indicated, for leafy vegetables in general, to keep the stress between 10-20 kPa, seeking the lower value for critical moments of development, where there is a greater water demand, such as the transplantation period and head forming. This way, Tangune *et al.* (2016) found that to obtain a larger and commercial fresh mass, inflorescence average diameter, total and commercial productivity for broccoli, irrigations should be performed when water stress in the soil is around 15 kPa, at 0.2 m depth. Higher stresses affect in a negative way productivity , fresh mass, diameter and circumference of the inflorescence.

In the first research, the cultivars Eikoo and Kinjitsu and the soil water stress ranges did not influence head dry mass (Table 2). In the second one, head dry masses and the 'Kinjitsu' root were not influenced by stress ranges (Table 2). Cultivar Eikoo had upper head dry mass under smaller stress ranges 13-17 and 23-27, which did not differ from each other. The stress ranges 33-37 and 43-47 differed from the first two 38.8 and 31.4 g/plant, respectively, but did not differ from each other.

In the first research, cultivars Eikoo and Kinjitsu and the soil water stress ranges did not influence the dry mass of roots (Table 2). This response was not observed in the second research, where a significant interaction was found and 'Eikoo' had lower root dry mass in lower stress ranges, 13-17 and 23-27 (25 and 28.3 g/plant, respectively). In addition, stress ranges 33-37 and 43-47 differed from the first two with 38.0 and 40.0 g/plant, respectively. This result pointed out a higher root growth in stress with less water availability and longer time interval between irrigations. The lower availability of water intensified root growth in depth, therefore accumulating higher dry mass. Thus, the energy expenditure required for root growth was not available for the dry mass head accumulation, which may have contributed to the aerial dry mass reduction in these stress ranges.

One of the main reasons that Chinese cabbage and other leafy vegetables demand constant irrigation to achieve optimum production is because leaf production is linked to leaf expansion, which is the water stress most sensitive physiological process. The sensitivity of Chinese cabbage leaf production to water stress is probably more intense due to its superficial root system, that is, more than 90% of the roots occur up to 35 cm deep in the soil and 20 cm wide around the stem (Averbeke & Netshithuthuni, 2010).

The soil water stress ranges did not influence 'Kinjitsu' roots growth, obtaining 20.4 g/plant, a lower value than that obtained with 'Eikoo' (32.8 g/plant) (Table 2). The absence of a significant difference in dry mass of roots is possibly related to the accumulation of similar dry mass of the head in 'Kinjitsu stress ranges, with no intense root development to meet the demand of aerial parts, as occurred in 'Eikoo'. This lower development may also be related to the 'Kinjitsu' low adaptation to summer-fall period climatic conditions. The soil water stress ranges did not influence head circumference and compactness (Table 3). Head circumference varied among cultivars, with 'Eikoo' superior to 'Kinjitsu'. This response is attributed to an increased head fresh mass obtained from 'Eikoo', being an intrinsic feature of the cultivar. Maseko *et al.* (2017) found that the Chinese cabbage fresh head production is related to environmental conditions (temperature), cultivar and planting density.

The compactness is highly appreciated by consumers and it is considered as an indication of a proper head formation. Values found in this study ranged between 2.5 and 3.5 in the first crop and 1.3 and 2.5 in the second one. In this way, there was a better head formation in the first culture, considering that values closer to five indicate better head quality (Seabra *et al.*, 2014).

Studying seven Chinese cabbage cultivars, Seabra *et al.* (2014) found compactness ranging from 1.0 to 4.3, and 'Kinjitsu' presented 2.9. This value is lower than that obtained in the first research (3.0), but higher than the

Table 3. Chinese cabbage plants heads circumference and compactness submitted to different ranges of soil water stress in two researches. Dois Vizinhos. UTFPR. 2016.

Soil water tension (KPa)	Heads circumference (cm)					
	2015			2016		
	Cv. Eikoo	Cv. Kinjitsu	Mean	Cv. Eikoo	Cv. Kinjitsu	Mean
13-17	38.8	36.4	37.6^{ns}	31.8	36.5	34.2^{ns}
23-27	38.6	37.8	38.2	35.3	34.0	34.6
33-37	38.5	32.5	35.5	37.8	30.3	34.0
43-47	37.6	38.0	37.8	38.3	33.3	35.8
Mean	38.4	36.2^{ns}	-	35.8 A*	31.0 B	-
CV (%)	8.9		-	10.6		-
	Compactness					
13-17	3.0	3.5	3.3^{ns}	1.8	1.8	1.8^{ns}
23-27	2.5	3.3	2.9	1.3	2.3	1.8
33-37	2.8	2.5	2.6	1.8	2.5	2.1
43-47	2.8	2.8	2.8	2.5	2.3	2.4
Mean	2.8	3.0^{ns}	-	1.8	2.2^{ns}	-
CV (%)	24.6		-	36.1		-

*Compactness notes ranging from 0 to 5 (0= total head absence; 1= head without a defined core; 2= outside core head and loose peripheral leaves; 3= defined core head and leaves with inceptive compaction in the periphery; 4= defined core head and compact peripheral leaves but with allowed visual individualization; 5- head with compact core and without visual individualization of the peripheral leaves. ^{ns} not significant by Scott-Knott test (p>0.05); *Means followed by same capital letters in the row and lowercase in the column do not differ statistically by Scott-Knott test (p>0.05).

Table 4. Efficiency in water use of Chinese cabbage plants submitted to different ranges of soil water stress. Dois Vizinhos. UTFPR. 2016.

Soil water tension (KPa)	Efficiency in water use (kg HDM/m³ of water)					
	2015			2016		
	Cv. Eikoo	Cv. Kinjitsu	Mean	Cv. Eikoo	Cv. Kinjitsu	Mean
13-17	32.7	42.1	37.4 a*	47.3	23.2	35.3a
23-27	17.6	18.3	18.0 b	32.2	16.5	24.4b
33-37	12.6	13.8	13.2 c	21.1	16.3	18.7b
43-47	10.5	14.4	12.4 c	14.2	10.1	12.2c
Mean	18.4 B	22.2 A	-	28.7 A	16.5 B	
CV (%)	11.1		-	22.1		-

*Means followed by same capital letters in the row and lowercase in the column do not differ statistically by Scott-Knott test (p>0.05).

one obtained in the second research (2.2) for 'Kinjitsu'. Considering that consumers prefer vegetables with good head formation, compactness is one of the most relevant features, which favors whitish leaves prevalence. For farmers, this is a feature that reduces transport volume and increases weight per plant.

In terms of numbers, compactness was lower in the second research, which could be associated with the early harvesting. There was an intense occurrence of erwinia (*Erwinia carotovora*) at the end of the cycle, mainly in 'Kinjitsu', which required early harvesting.

For water use efficiency, cultivars responded differently. In the first research, 'Kinjitsu' was more efficient (22.2 kg m^{-3}), compared to 'Eikoo', which showed higher efficiency (28.7 kg m^{-3}) in the second research (Table 4). 'Eikoo's higher efficiency during the second research (summer) is the result of its higher productive capacity under higher temperature conditions in that period.

The soil water stress ranges influenced the water use efficiency in both researches (Table 4). The highest were 42.1 kg m^{-3} in the first research and 47.3 kg m^{-3} in the second, for Kinjitsu and Eikoo, respectively, in the stress range 13-17 kPa. Water use efficiency decreased with increasing soil water stress ranges. In plantings with lower water availability, water consumption was higher in both researches and the productivity was not increased, resulting in lower hydric efficiency. Likewise, in broccoli crop, the use of different soil water stresses (15, 30, 45, 60, 75 and 90 kPa) did not result in water use efficiency change (Tangune *et al*., 2016).

Averbeke & Netshithuthuni (2010) found in studies with different irrigation scheduling practices that Chinese cabbage is not efficient in water use, and in two-thirds of its growth period, the first six to seven weeks, water use was mostly destined for soil surface evaporation due to the small size and smaller leaf area of the plants. High frequency irrigation scheduling did not result in high production but led to a considerable amount of water drained to the rooting zone. The authors suggest that irrigation methods, that allow better control over the amount of water applied per irrigation event, would make water use more efficient.

In summertime, cultivar Eikoo was more productive and in the fall-winter period, the two cultivars, Eikoo and Kinjitsu, can be cultivated in protected environment due to favorable environmental conditions. The stress range between 13-17 kPa allowed higher productivity and efficiency in water use.

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