Strategies for reducing winter water stress in rainfed avocado orchards under changing climatic conditions in Southwestern São Paulo State

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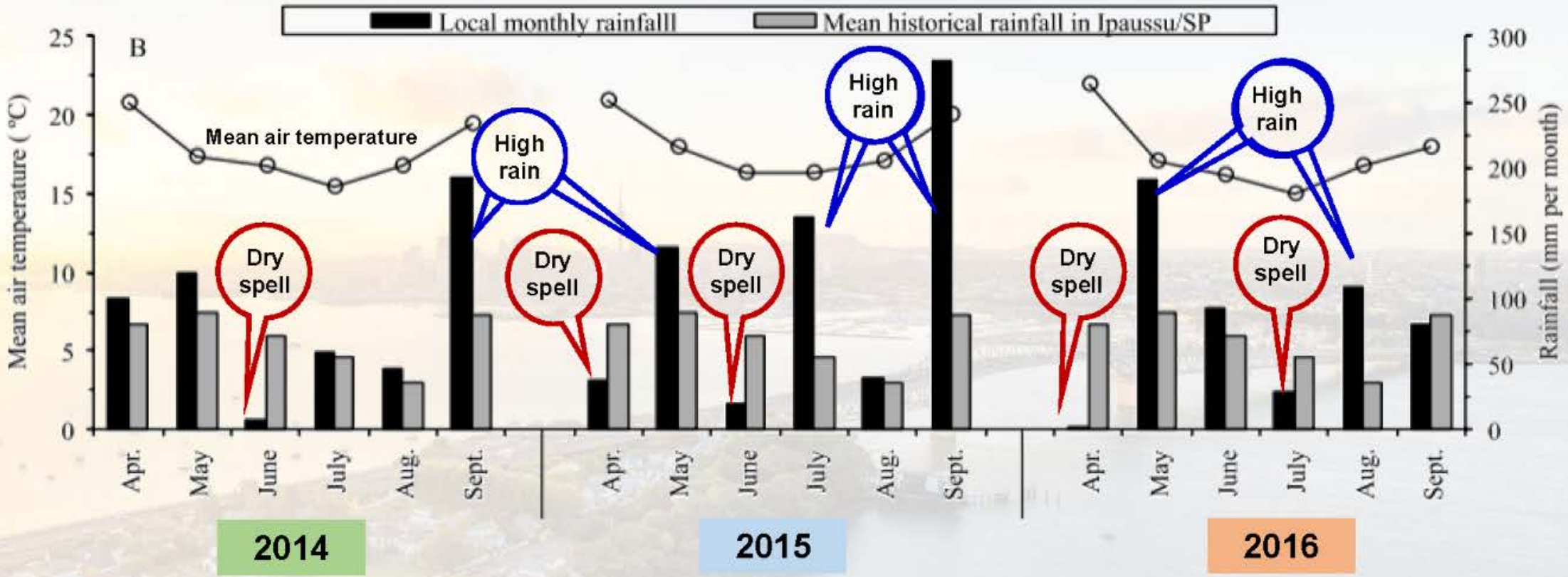
Rainfed avocado cultivation in Brazil

- Rainfed cultivation is a common practice in the main avocado growing regions of Brazil.
- Severe water stress occurring from the beginning of autumn (April) until early spring (September) coincides with the stages of floral bud differentiation, flowering, initial fruit set, and spring vegetative flush of all the commercial cultivars, and reduces fruit yield and quality.

Rainfed Avocado Cultivation Under Changing Climatic Conditions



Local monthly rainfall, mean historical rainfall and mean air temperature in the 2014-2016 period in Ipaussu, southwestern São Paulo state, Brazil.

Material and Methods

- During a 4-year period, **three different crop management strategies for ameliorating plant water stress** were evaluated during the dry period in 'Hass', 'Quintal' and commercial avocado orchards grown in clayey soils.

(i) **Supplemental irrigation in the autumn-winter dry period** (April through September, applied at 2 rates (2,545 and 5,090 m^3 ha^{-1}), and compared with non irrigated trees.

(ii) **Applications of soil conditioners** (chip woods, gypsum and lime) to the rows twice a year (early spring and late summer).

(iii) **Foliar sprayings of kaolin particle films** in May-July in orchards and nursery trees.

Material and Methods

- Over a 4-year period (2014-2017), the following variables were measured:
  - Soil water content;
  - Sap flow;
  - Leaf water potential; leaf color and chlorophyll content;
  - Leaf and fruit abscission rates;
  - Tree size;
  - Shoot and trunk growth
  - Fruit yield and quality.

Results

Supplemental irrigation with 2,545 m^3 ha^{-1} applied from April through September in the 2014-2016 triennium **improved leaf water status and increased leaf area index** of 'Quintal' and 'Hass' avocados, as compared with non-irrigated plants.

Predawn Leaf Water Potential (MPa)

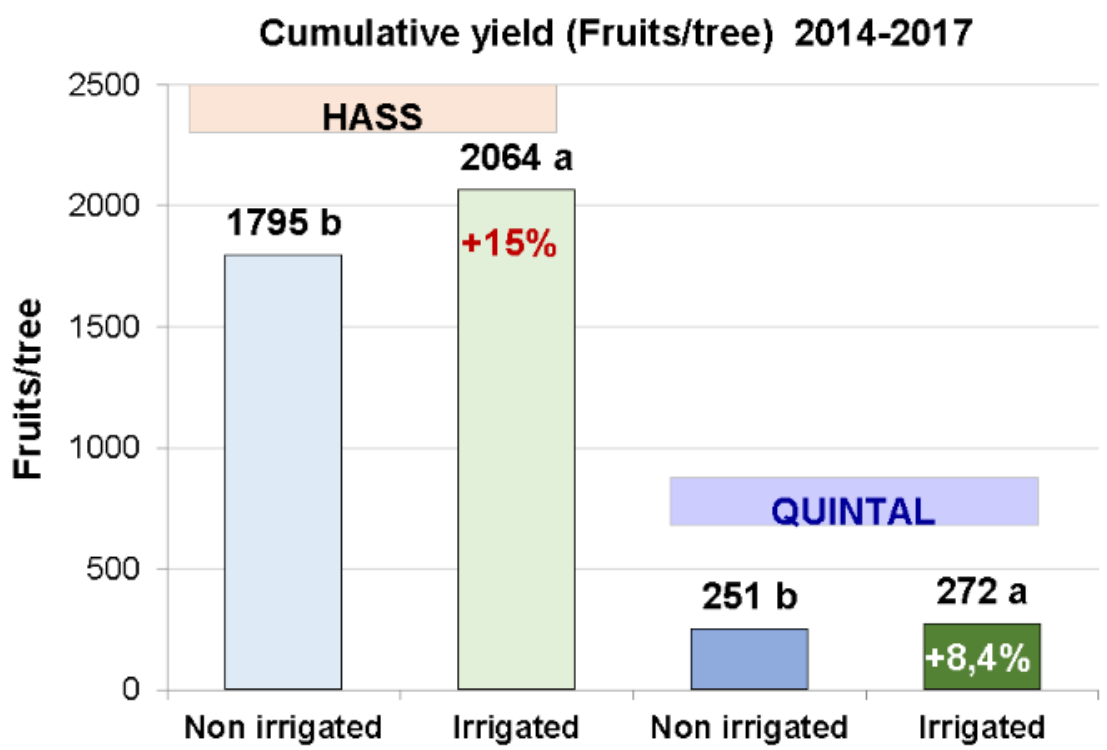
Cultivar	Treatment	2014		2015		2016		Mean	
HASS	Non irrigated	-0.08	a	-0.11	a	-0.15	a	-0.11	a
	Irrigated	-0.07	a	-0.08	b	-0.13	a	-0.09	a
QUINTAL	Non irrigated	-0.14	a	-0.14	a	-0.15	a	-0.14	a
	Irrigated	-0.13	a	-0.10	b	-0.12	b	-0.12	b

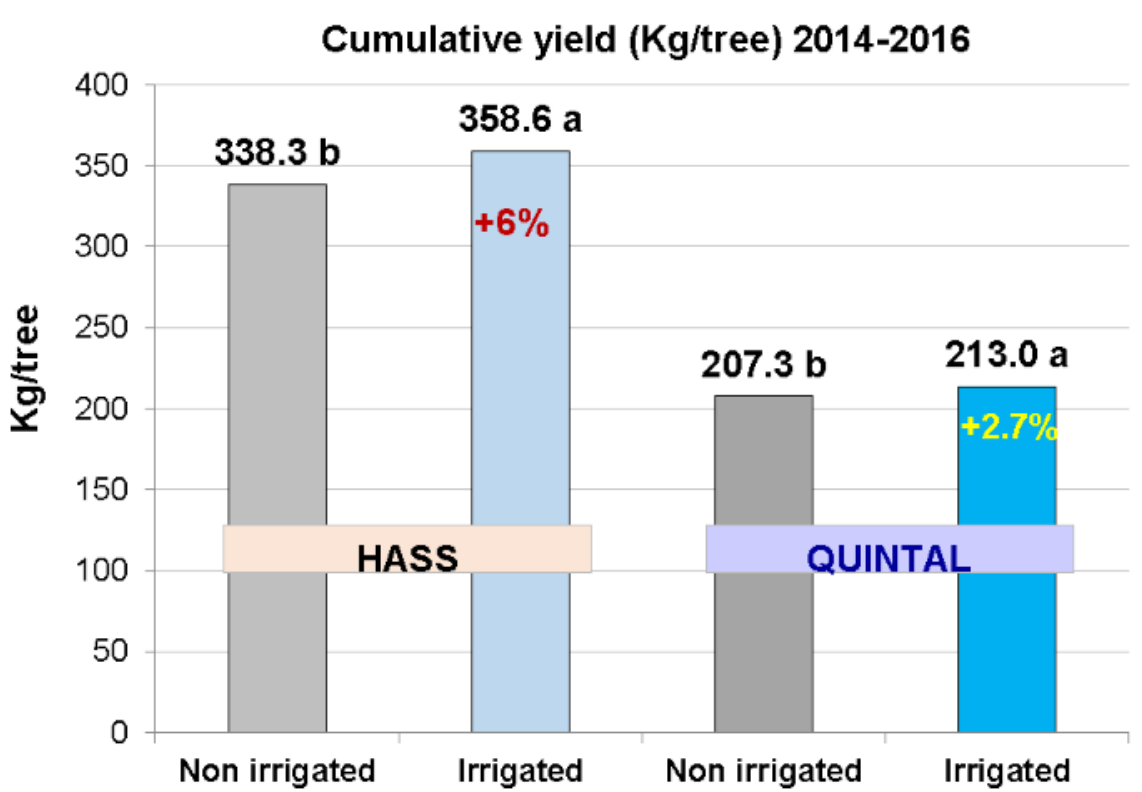
Leaf Area Index (LAI)

Cultivar	Treatment	2014		2015		2016		Mean	
HASS	Non irrigated	2.31	b	2.72	a	2.93	b	2.93	b
	Irrigated	3.00	a	2.68	a	3.36	a	3.36	a
QUINTAL	Non irrigated	4.08	b	2.16	a	1.54	b	1.85	b
	Irrigated	4.22	a	2.16	a	1.76	a	1.96	a

Results

Supplemental irrigation with 2,545 m^3 ha^{-1} from April through September increased **the average fruit yield in 'Quintal' and 'Hass' avocados**, as compared with non-irrigated trees.





Material and Methods

Applications of soil conditioners - Fazenda Campo de Ouro, Piraju, São Paulo State

- In 2014-2017, different mulch treatments were applied in an **adult rainfed Hass avocado orchard** in a clayey soil twice a year, in October (beginning of the rainy spring/summer period) and February (end of summer):

T1: Grass clippings mowed with ecological inter-row mower.

T2: Avocado wood chips.

T3: Avocado wood chips + mix of 1:1 gypsum:lime

T4: Bare soil (natural mulch was removed).


T1: Ecological inter-row mower


T2: Avocado wood chips

T4: Avocado wood chips + gypsum

T3: Bare soil (natural mulch removed)

Results

Applications of soil conditioners - Fazenda Campo de Ouro, Piraju, São Paulo State

SOIL MOISTURE CONSERVATION during the autumn-winter dry period:

Treatment	% Soil Water Content (g/g)				
	8 Aug 2015	4 Sep 2015	25 Sep 2015	15 Sep 2016	Mean
T1: Grass clippings	**24.9**	**18.5**	**20.8**	**20.4**	**21.2 a**
T2: Avocado wood chips	**20.9**	**18.3**	**24.2**	**23.0**	**21.6 a**
T3: Avocado wood chips + 1:1 gypsum:lime mix	16.4	17.2	21.8	22.0	19.4 b
T4: Bare soil (natural mulch removed)	17.6	19.0	25.2	20.7	20.6 b

IMPROVED LEAF WATER POTENTIAL during the autumn-winter dry period:

Treatment	Midday Leaf Water Potential (MPa)			
	6 Sep 2014	8 Aug 2015	15 Jul 2016	Mean
T1: Grass clippings	**-0.53 c**	**-0.64 c**	**-0.63 b**	**-0.60 c**
T2: Avocado wood chips	**-0.70 b**	**-0.74 b**	**-0.60 b**	**-0.68 bc**
T3: Avocado wood chips + 1:1 gypsum:lime mix	**-0.64 bc**	**-0.95 a**	**-0.68 a**	**-0.76 b**
T4: Bare soil (natural mulch removed)	-0.86 a	-0.95 a	-0.68 a	-0.83 a

✓ Mulching the row lines improved soil water content and plant water status.

Results

Applications of soil conditioners - Fazenda Campo de Ouro, Piraju, São Paulo State

HIGHER LEAF CHOROPHYLL CONTENT during the autumn-winter dry period:

Treatment	Leaf chlorophyll content (ICF units)			
	19 jun 2014	8 ago 2015	15 jul 2016	Mean
T1: Grass clippings	**59.5 a**	**70.4 a**	**54.9 a**	**61.6 a**
T2: Avocado wood chips	**59.7 a**	**71.2 a**	**54.2 ab**	**61.7 a**
T3: Avocado wood chips + 1:1 gypsum:lime mix	57.2 b	70.5 a	53.7 ab	60.5 b
T4: Bare soil (natural mulch removed)	59.4 a	69.7 a	52.0 b	60.4 b

INCREASED LEAF AREA INDEX during the autumn-winter dry period:

Treatment	Leaf Area Index (LAI)		
	21 Apr 2014	19 May 2015	8 Oct 2016
T1: Grass clippings	**3.11 a**	**4.03 a**	**3.39 a**
T2: Avocado wood chips	**3.37 a**	**4.05 a**	**3.12 ab**
T3: Avocado wood chips + 1:1 gypsum:lime mix	**2.95 b**	**3.55 b**	**3.12 ab**
T4: Bare soil (natural mulch removed)	2.67 b	3.60 b	2.79 c

✓ Mulching the row lines improved leaf chlorophyll content and leaf area index

Results

Applications of soil conditioners - Fazenda Campo de Ouro, Piraju, São Paulo State

Treatment	Kg/tree			
	20 jun 2014	18 May 2015	14 Apr 2016	Cumulative/ Mean
T1: Grass clippings	137.1 b	23.0 b	47.0 b	204.0 c
T2: Avocado wood chips	**149.0 a**	**27.9 a**	**56.9 a**	**233.8 a**
T3: Avocado wood chips + 1:1 gypsum/lime mix	119.8 c	**31.9 a**	**52.5 ab**	204.2 c
T4: Bare soil (natural mulch removed)	146.5 a	9.7 c	**57.3 a**	213.5 b
	Fruits/tree			
T1: Grass clippings	606 b	73 b	224 c	904 c
T2: Avocado wood chips	**717 a**	**139 a**	**307 a**	**1.162 a**
T3: Avocado wood chips + 1:1 gypsum/lime mix	539 c	**138 a**	268 b	945 b
T4: Bare soil (natural mulch removed)	683 a	43 c	**325 a**	**1050 ab**
	Yield Efficiency (kg/m3)			
T1: Grass clippings	2.71 ab	0.31 a	0.57 c	1.20 ab
T2: Avocado wood chips	**3.23 a**	**0.32 a**	**0.84 a**	**1.46 a**
T3: Avocado wood chips + 1:1 gypsum/lime mix	1.96 c	**0.44 a**	0.59 c	1.00 b
T4: Bare soil (natural mulch removed)	2.29 b	0.11 b	0.70 b	1.03 b
	Individual fruit weigth (g/fruit)			
T1: Grass clippings	**249.2 ab**	**238.3 a**	203.5 b	**230.3 a**
T2: Avocado wood chips	**214.4 c**	**231.1 b**	**208.9 ab**	218.1 b
T3: Avocado wood chips + 1:1 gypsum/lime mix	**257.2 a**	**238.7 a**	**213.5 a**	**236.5 a**
T4: Bare soil (natural mulch removed)	229.3 b	220.4 c	204.9 b	218.2 b

Material and Methods

Foliar sprayings of kaolin particle films

- In 2014-2017, **3 different kaolin formulations** were monthly sprayed in **May, June and July** (autumn-winter dry period) in commercial 'Breda' and 'Margarida' avocado orchards under rainfed cultivation.
- Additionally, in 2016, 2 kaolin formulations were applied in **nursery trees** in May, June and July.

Leaf gas exchange variables were measured with an Infrared Gas Analyzer (IRGA).

T1: Control (water).

T2: Kaolin #1 (prepared with 33 g/L 200 µ-kaolin + 0.5 ml/L soluble silicate + 0.25 g/L zinc chelate + 0.075 mL/L Silwett L-77 Ag silicon surfactant).

T3: Kaolin #2 (commercial sun protector formulation, Protecsol®, Anasac, Chile)

T4: Kaolin #3 (commercial sun protector formulation, Nublado® /Purshade®, Consagro Ltda., Brazil)

Results

Foliar sprayings of kaolin particle films in commercial avocado orchards in 2014-2015

Trials in commercial orchards: Breda avocado cultivar, Midday Leaf Water Potential

Treatment	Midday Leaf Water Potential (MPa)			
	26 Jul 2014	5 Sep 2014	27 Oct 2014	Mean
T1: Control (water)	-0.37	-0.65	-1.05	-0.69 a
T2: Kaolin #1 (prepared)	-0.26	-0.46	-1.13	-0.61 b
T3: Kaolin #2 (Protecsol®)	-0.31	-0.47	-0.98	-0.59 b
T4: Kaolin #3 (Nublado/Purshade®)	-0.17	-0.55	-0.76	-0.49 b

Trials in commercial orchards: Margarida avocado cultivar, Leaf Color Index (*h°/L×C)*

Treatment	Leaf Color Index (h^o/L×C)	
	Breda	Margarida
	12 Set 2014	31 Jul 2015
T1: Control (water)	0.43 b	0.45 c
T2: Kaolin #1 (prepared)	0.55 a	0.62 a
T3: Kaolin #2 (Protecsol®)	0.62 a	0.56 b
T4: Kaolin #3 (Nublado/Purshade®)	0.40 b	0.50 b

Results

Foliar sprayings of kaolin particle films in avocado nursery trees - Year 2016

- ✓ Except on Net Photosynthesis Rate and Leaf Color, 'Hass' and 'Margarida' avocado seedlings showed **opposite leaf gas exchange responses to kaolin foliar sprayings.**
- ✓ In both cultivars, successive sprayings with both kaolin film formulations **increase Leaf Photosynthesis**.

Treatment	Net Photosynthesis Rate (A) µmol [CO_2] m^{-2} s^{-1}		Stomatal Conductance rate (g_s) µmol [CO_2] m^{-2} s^{-1}		Transpiration Rate (E) µmol [H_2O] m^{-2} s^{-1}	
	'Hass'	'Margarida'	'Hass'	'Margarida'	'Hass'	'Margarida'
T1 (control)	6.05 aB	10.91 aA	0.089 aA	0.098 aA	1.563 bB	3.735 aA
T2 (kaolin Incomgel®+Zn+Si)	7.02 aB	12.05 aA	0.118 aA	0.070 aA	2.693 abA	2.778 aA
T3 (kaolin Protecsol® (Anasac)	9.42 bA	13.05 bA	0.220 bA	0.045 bB	4.460 aA	2.035 bB
Mean	7.50 B	12.00 A	0.142 A	0.071 B	2.905 A	2.849 A

Treatment	*Leaf-Air Temperature Tf-Ta* (°C)		*Leaf Chlorophyll Content* (ICF units)		*Leaf Color Index* h^o/LC	
	'Hass'	'Margarida'	'Hass'	'Margarida'	'Hass'	'Margarida'
T1 (control)	0.728 aA	0.648 bA	63.63 aA	54.80 aB	0.29 bA	0.26 bA
T2 (kaolin Incomgel®+Zn+Si)	0.428 aA	0.588 bA	63.20 aA	52.60 aB	0.56 bA	0.48 abA
T3 (kaolin Protecsol®)	-0.235 bB	1.115 aA	61.50 aA	57.45 aA	1.53 aA	0.76 aB
Mean	0.307 B	0.783 A	62.78 A	54.95 B	0.79 A	0.35 B

Results

Foliar sprayings of kaolin particle films in avocado nursery trees - Year 2016

	A/g_s^* (µmol mol-1)		A/E (WUE) (µmol [CO_2] m^{-2} s^{-1})		A/C_i (µmol m-2 s-1 Pa-1)	
Treatment	**'Hass'**	**'Margarida'**	**'Hass'**	**'Margarida'**	**'Hass'**	**'Margarida'**
T1 (control)	110.18 aA	113.30 bA	4.830 aA	2.930 cB	0.0025 aB	0.053 bA
T2 (kaolin Incomgel®+Zn+Si)	59.28 abB	186.79 abA	**2.583 bB**	**4.560 bA**	0.0025 aB	**0.125 aA**
T3 (kaolin Protecsol® (Anasac)	**43.67 bB**	**313.34 aA**	**2.125 cB**	**6.723 aA**	0.0028 aB	**0.095 aA**
Mean	**71.04 B**	**204.48 A**	**3.199 B**	**4.738 A**	**0.0026 B**	**0.091 A**

- In 'Hass' seedlings, both kaolin formulations significantly reduced the A/gs and A/E (Water Use Efficiencies) values. This effect was compensated by the increased leaf reflectance and lower leaf temperature that may effectively reduce foliar heat stress during drought periods.
- In 'Margarida' seedlings, the increased A/E and A/Ci (carboxylation efficiency) resulting from successive kaolin applications is particularly important under rainfed growing conditions, and indicate a better adaptation of this cultivar to drought, as compared to 'Hass'.

Results

Under rainfed cultivation or during drought conditions, the application of **water, wood chip mulch and foliar sprayings with kaolin particle films** are effective strategies for ameliorating plant water stress and increasing fruit yield and quality in avocado orchards.

Questions

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