Field Production

Cheryl Boyer

Section Editor

The Tree Production Rotation Problem

Forrest Stegelin

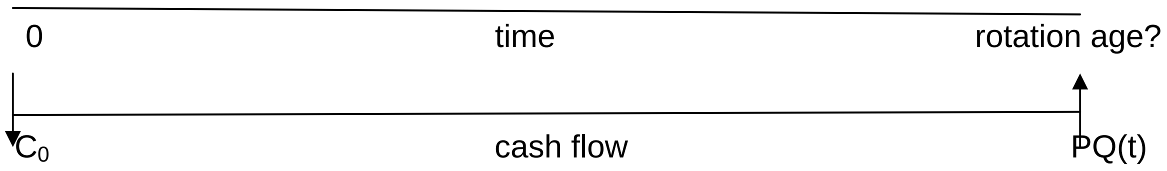
Agriculture and Applied Economics, 312 Conner Hall, University of Georgia
Athens, GA 30602-7509

stegelin@uga.edu

Index Words: Net present value, nursery production, multi-year harvest/investment analysis

Significance to Industry: When management of a field production nursery either establishes or expands a block of trees as seedlings or liners, the manager is embarking on a multi-year investment analysis. As time passes and the trees grow in the field nursery, landscapers or other customers may pick and choose among the rows of trees in the block a few, select quality specimens that meet their needs. However, the entire block is not purchased, and the remaining trees continue to grow in caliper, height, vegetative growth or canopy, and form into the next marketing season. This scenario occurs repetitively season after season. At what point in time is it more economically feasible to close out the block with its few remaining mature trees, and start anew with young seedlings of either the same or a different species? What is the opportunity cost of time in the tree production rotation problem?

Nature of Work: The simple solution is to view the problem as a single rotation problem whereby all the trees in the block are harvested at the same time – at the same price and incurring the same costs throughout the production period – maximizing the net present value of the final harvest. The management regime for a single rotation is defined by an initial fixed cost for establishing a block and then determining when to dig or harvest the trees.



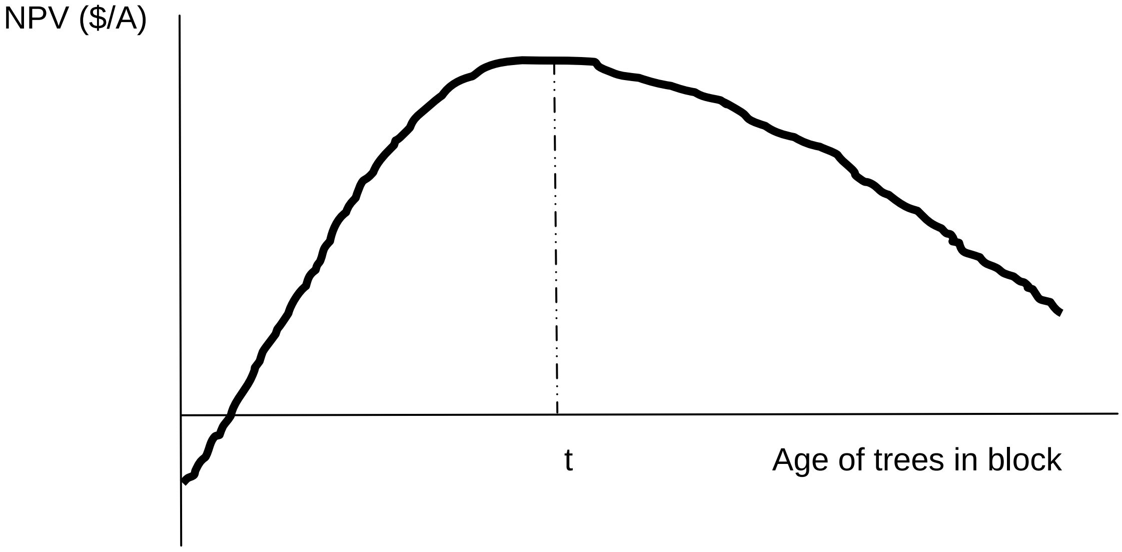
Net present value (NPV) is the current, net value of an investment, taking the time value of money into consideration when evaluating costs and returns. NPV provides a measurement of the net value of a multi-year investment in today's dollars by using the discounting formula to value the projected cash flows. The NPV of an investment is the present value of the cash inflows (revenue from marketing and selling trees from a block, in this situation) minus the present value of the cash outflows (costs and expenses from establishing, growing, and harvesting from the block of trees). A formula for NPV is:

$$NPV = \frac{P*Q(t)}{(1+i)^t} - \frac{C(t)}{(1+i)^t}$$

Where P = output price;
Q(t) = production quantity in time period t;
P*Q(t) = revenue or value of harvest at time t;
I = real interest rate or discount rate during time period t;
C(t) = costs of establishing block plus operational costs for time period t.

The costs are known as recorded by the accountant in the formal financial statement called the income statement (Revenue minus Expenses equals Net Income (Loss)). The price is per item, as realized when the quantity of trees are sold. However, the discount rate is an estimate of the real interest rate during the observed time period. Investment studies show investments of 5 – 10 years (the growth period) in field production nurseries have discount rates of 8 – 11 percent (shorter time spans have lower discount rates, as risk window is narrower).

As trees in a block age or mature, the cash inflow value is not infinite nor is it linear with respect to costs of maintenance and growth; the net positive value of the block decreases beyond some peak. What is the number of years (t) and which discount rate to use?



There are several concerns associated with interpreting the financially optimal single rotation age of trees in a block, as described above. First is the difference between the age of the trees in the block and the timeframe used to evaluate or calculate the NPV. If a block is established with two-year old seedlings, the trees are actually two years older than the investment time frame. Second is the investment decision criteria of accepting if the NPV is greater than zero. If the NPV > 0, digging at time t returns the desired discount rate plus the present value of additional net revenue, but foregoes larger NPVs observable at later time periods before the peak in the cash flow stream. Third is that biological production and rotation makes no statements concerning optimizing profits, but rather quality. Fourth, in economics maximization is defined if a marginal condition is set equal to zero, such as marginal costs equal marginal revenue to maximize profits. This leads to the decision of harvesting or digging today or waiting until next season, thereby defining the opportunity costs in terms of revenues and costs.

Results and Discussion: The problem of deciding when to start anew on a block is compounded with the multi-year production regime whereby the block is thinned as trees are dug and sold during a marketing season, leaving the remaining trees to increase in value or price with each succeeding season, the quantity sold is not consistent or constant from season to season for each size or age of tree, growth spurts occur at different times for different species under different production regimes, the quality of remaining trees may not be uniform (inconsistent sales and thinning), and the appropriate discount rates are difficult to determine. The time element solution also varies with each species of tree in production in the block, as production value is influenced by the spacing, timing, and species within a block. Determining the economic solution to the investment question requires aggregation of multiple scenarios (marketing seasons) whereby prices, quantities, costs, and discount rates change with each passing season.

The multi-year NPV of a block of trees in a field production nursery equals the ($PV_{i,t}$ inflows – $PV_{i,t}$ outlflows) for establishment through first marketing season plus ($PV_{i,t}$ inflows – $PV_{i,t}$ outflows) for second marketing season plus … , for the total number of years t in production.

Unless management has an accurate forecast of the demand (price, quantity), quality, and real interest rates for each marketing season over a five to ten year investment time horizon, determining when the net present value is maximized is merely an estimate. If the management has no other profitable opportunities, best to leave the block intact until the last tree is dug or removed. If other opportunities exist (demand for other species or other sizes), remove the remaining trees and reestablish a new block, if the NPV calculations of the new planting opportunity in the block exceed the NPV of the current block of tree production. This requires a dynamic evaluation – a much easier analysis in forestry economics than in horticultural economics.

Literature Cited:

Avent, Tony. *So You Want to Start a Nursery*. 2003. Timber Press.

Barnard, Freddie, Jay Akridge, Frank Dooley and John Foltz. *Agribusiness Management*, 4th edition. 2012. Routledge.

Johnson, Larry. *Nursery Management*. University of Tennessee, PB 1403. 1991.

Wagner, John E. *Forestry Economics*. 2012. Routledge.

Interaction between the Mexican Fan Palm (*Washingtonia robusta* H. Wendland) and root endophytes: Effects of Vesicular Arbuscular Mycorrhiza Fungi and Plant Growth Promoting Rhizobacteria on Drought Stress

Andrés Adolfo Estrada-Luna[1,2]; Victor Olalde-Portugal[2]; Jorge Molina Torres[1], and
Enrique Ramírez Chávez[1]

[1]Escuela de Agronomía. Universidad De La Salle Bajío. Av. Universidad 602
Col. Lomas del Campestre. León, Gto., México. C.P. 37150.
[2]CINVESTAV-IPN. Km. 12.5. Libramiento Norte, Carretera Irapuato-León. Irapuato
Gto., México. C.P. 36821.

aestradaluna@yahoo.com

Index Words: water stress, palms, endophytes, PGPRs, mycorrhiza, Mexican Washingtonia, Arecaceae

Significance to Industry: The nursery industry stands to benefit from naturally occurring soil microorganisms including mycorrhizal fungi symbionts and soil rhizobacteria, which enhance plant health when properly interacting with roots, especially during common naturally occurring environmental stresses. The benefits of mycorrhizal symbiosis and plant growth promoting rhizobacteria (PGPR) are of interest for low input-sustainable agricultural systems at greenhouse, nursery production and field production. In this study, performed under container conditions, we demonstrated the effects of water deficit on *Washingtonia robusta* plants and the activity of selected endophytes on plant protection.

Nature of Work: Plants growing under natural conditions are not isolated; they intimately interact with harmful and beneficial macro and microorganisms above and underground. Beneficial microorganisms including soil fungi and bacteria, may fix atmospheric nitrogen (N), decompose organic wastes, detoxify pesticides, suppress soil-borne pathogens, participate in nutrient cycling, and produce bioactive compounds (vitamins, hormones and enzymes), that stimulate plant growth and fitness (1). However, the interaction between roots and microorganisms becomes particularly relevant when plants face common biotic and environmental stresses.

Palms are woody perennial monocots that interact with growth-promoting rhizobacteria and form mycorrhizas with vesicular arbuscular fungi (2, 3, 4). In particular, *Washingtonia robusta* is a multipurpose ornamental plant used for reforestation, as natural barrier or to recover eroded soils. Data on the biology (5), seed germination (6), and culture (7) have recently been published; however, no information exists on the effects of its interaction with PGPRs and mycorrhizas on water deficit. Because of this, any knowledge to understand the endophyte-root physiology may be applied on an ecological context for sustainable commercial-oriented systems.

A glasshouse study was conducted to evaluate the effects of water stress and two selected endophytes on the physiology of *Washingtonia robusta* young plants. The factorial experiment included 8 treatments resulting from the combination of the two levels of the water regime evaluated: well watered and water stress, and the four levels of the presence of endophytes: control, inoculation with PGPR [*B. subtilis* BEB-Mz], inoculation with mycorrhizal fungi (VAMF) [vesicular arbuscular], and inoculation with PGPR+VAM. The Mexican fan palm seedlings were obtained through seed germination (6) and cultured for 45 days. During transplantation, the PGPR was inoculated by pipetting 30 mL of liquid inoculum on the root system ($5X10^6$ cells) and the VAMF (Mexican consortium Selva including *Glomus constrictum*, *G. fasciculatum*, *G. tortuosum*, and *Acaulospora scrobiculata*), was applied by banding the inoculum just below the roots ($1X10^3$ fungal spores). Fertilization was provided with the Long Ashton nutrient solution (8) modified to supply 22ppm of phosphorus (P). The water stress treatment was imposed by reducing irrigation for 20 days until 5Mpa was reached. At that time, root colonization by VAMF and PGPR was determined and photosynthesis measurements were taken. Gas exchange including net photosynthesis (λ), transpiration (E), and stomatal resistance (g_s) was measured using a LI-6200 Portable Photosynthesis System (Li-COR Inc., Lincoln, Neb.). Maximum quantum efficiency of Photosystem II (Fv/Fm) and Performance Index (PI) were determined with a chlorophyll fluorescence system (Pocket Plant Efficiency Analyser) (Hansatech Instruments Ltd, Norfolk, UK). Growth measurements including leaf number, total shoot length (cm), root, shoot, total plant fresh (FM) and dry mass (DM) (g) were evaluated in all treatments. Mineral nutrient analysis was performed from the shoot part of the plants (four mature and expanded leaves) to determine total concentration of all macronutrients and some micronutrients including iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn). Biochemical determinations included soluble carbohydrates, total and specific aminoacids, total chlorophyll, and chlorophyll *a* and *b*.

Results and Discussion: Data of root colonization by VAMF and PGPR indicated that *Washingtonia robusta* was able to establish mycorrhizas and interact with PGPRs. Our results suggest that *Washingtonia robusta* is highly dependent of the mycorrhiza establishment because high levels of total colonization were observed. The PGPR population was negatively affected by the presence of VAMF and the severe water deficit imposed (5MPa), which also reduced the percentage of fungal vesicles and arbuscules (Fig. 1). The nutrient status of the plants was enhanced by the VAMF, which increased concentrations of P and K; however, the non-inoculated plants showed significantly higher concentrations of Ca and Mn (Table 1). In general, the water stress promoted drastic changes on plant metabolism, functioning, and growth. Plants suffering water stress closed the stomata and a substantial reduction in the efficiency of the photosynthetic machinery and the rate of carbon dioxide (CO_2) fixation was observed (Table 2). The plant growth was increased by endophytes, especially by mycorrhizal fungi (Tables 3 and 4). Chlorophyll *a*, *b* and total content was reduced by water stress (Table 5). In contrast, sucrose, galactose and aminoacid concentrations were dramatically increased (Tables 6 and 7). Our observations suggest that *Washingtonia robusta* is genetically resistent to water stress, however, the interaction between the roots and the two endophytes attenuate all negative effects. The establishment of mycorrhizas seem to have a critical role in plant response and survival when facing lack of water because significant benefits were obseved. In contrast to this, the bacteria seem to play a secondary role. Our recommendation to growers is to include the inoculation with selected microorganisms in their propagation schemes becuase they enhance plant performance and give a better price to their products.

Acknowledgements: Authors want to thank for the economical support provided by the Universidad De La Salle Bajío through the Office of the Research Council.

Literature Cited

1. Dimkpa C, T Weinand, F Asch. 2009. Plant-rhizobacteria interactions alleviate abiotic stress conditions. Plant, Cell & Environment 32: 1682-1694.
2. Pérez-García A, D Romero, A de Vicente. 2011. Plant protection and growth stimulation by microorganisms: Biotechnological applications of Bacilli in agriculture. Current Opinion in Biotechnology 22: 187-193.
3. St. John TV. 1988. Prospects for application of vesicular-arbuscular mycorrhizae in the culture of tropical palms. Adv. Econ. Bot. 6: 50–55.
4. Al-Whaibi MH, AS Khaliel. 1994. The effect of Mg on Ca, K and P content of date palm seedlings under mycorrhizal and non-mycorrhizal conditions. Mycoscience 35: 213-217.3.
5. Ishihata K. And Murata H. Morphological studies in the genus *Washingtonia*: On the intermediate form between *Washingtonia filifera* (L. Linden) H. Wendland and *Washingtonia robusta* H. Wendland. Ibusuki Experimental Botanic Garden. 331-354pp.
6. Estrada-Luna AA, A Rojas García. 2010. Improving germination of seeds of Mexican fan palm (*Washingtonia robusta* H. Wendland) through physical and chemical treatments. 2010 SNA Research Conference 56: 314-318.
7. Estrada-Luna AA, HC Morales Torres, V Olalde-Portugal, E Camarena Olague, JC Romero Gonzalez. 2011. Effect of Cell Size on Growth and Physiology of Mexican Fan Palm (*Washingtonia robusta* H. Wendland: Arecaceae) Seedlings. 2011 SNA Research Conference 56: 389-392.
8. Hewitt EJ. 1966. Sand and water culture methods used in the study of plant nutrition. Technical communication No. 22, Commonwealth Agricultural Bureaux, Farnham Royal, UK.

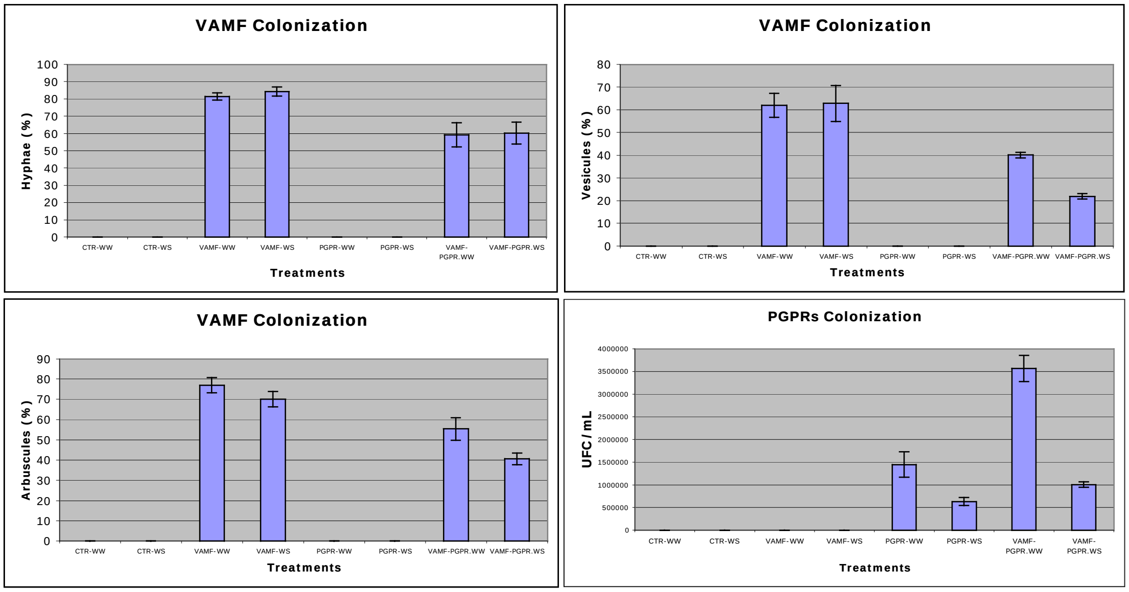


Figure 1. Root Colonization of *Washingtonia robusta* H. Wendland by Vesicular Arbuscular Mycorrhizal Fungi and plant growth promoting rhizobacteria.

Table 1. Effect of VAMF, PGPRs and water level on plant nutrient status of *Washingtonia robusta* H. Wendland plants 5 months after inoculation.

Endophyte	Water Level (mM)	P%	K%	Ca%	Mn ppm
CTR [+]	WW	0.09	0.66	0.82	141.64
VAMF °	WW	0.16	1.00	0.65	93.42
PGPR •	WW	0.13	0.79	0.68	122.89
VAMF-PGPR	WW	0.12	0.71	0.66	111.83
CTR	WS	0.10	0.66	0.77	153.08
VAMF	WS	0.15	0.92	0.69	122.11
PGPR	WS	0.08	1.05	0.83	129.08
VAMF-PGPR	WS	0.14	0.85	0.60	101.31
Significance:					
Water Level		NS	NS	NS	NS
Endophyte		***	*	**	**
Endophyte X Water Level		*	NS	NS	NS

[+] CTR: Control (Non Inoculated)

°VAMF: Vesicular Arbuscular Mycorrhizal Fungi

• PGPR: Plant Growth Promoting Rhizobacteria

WW= Well Watered

WS= Water Stressed

NS= Non significant

*= Significant (0.05)

**= Significant (0.01)

***= Significant (0.001) n=3

Table 2. Effect of VAMF, PGPRs and water level on Photosynthesis and Gas exchange capacity of *Washingtonia robusta* H. Wendland plants 5 months after inoculation.

Endophyte	**Water Level**	**Fv/Fm**	**PI**	**E (mmol/m^{-2}/s^{-1})**	**λ (μmol/m^{-2}/s^{-1})**	**r_s (s/cm^{-1})**
CTR[+]	WW	0.81	3.47	0.0059	16.24	1.34
VAMF[°]	WW	0.83	4.98	0.0056	15.07	1.57
PGPR[•]	WW	0.82	4.06	0.0022	7.68	2.37
VAMF-PGPR	WW	0.82	3.58	0.0086	20.74	0.98
CTR	WS	0.76	1.88	0.0589	1.60	58.07
VAMF	WS	0.73	1.41	0.0003	5.15	90.87
PGPR	WS	0.72	1.31	0.0463	5.48	47.63
VAMF-PGPR	WS	0.72	1.18	0.1842	2.97	85.63
Significance:						
Water Level		***	***	*	***	***
Endophyte		NS	**	NS	***	NS
Endo X Water Level		**	***	NS	***	NS

[+] CTR: Control (Non Inoculated)

[°] VAMF: Vesicular Arbuscular Mycorrhizal Fungi

[•] PGPR: Plant Growth Promoting Rhizobacteria

WW= Well Watered
WS= Water Stressed
NS= Non significant
*= Significant (0.05)
**= Significant (0.01)
***= Significant (0.001) n=4

Table 3. Effect of VAMF, PGPRs and water level on Growth of *Washingtonia robusta* H. Wendland plants 5 months after inoculation.

Endophyte	**Water Level**	**Root Dry Weight (g)**	**Shoot Dry Weight (g)**	**Leaf Dry Weight (g)**	**Shoot Dry Weight (g)**	**Plant Dry Weight (g)**
CTR [+]	WW	15.90	5.96	9.91	15.87	31.77
VAMF °	WW	12.76	8.50	12.34	20.84	33.60
PGPR •	WW	11.70	6.68	9.35	16.02	27.72
VAMF-PGPR	WW	10.74	7.47	11.48	18.96	29.70
CTR	WS	15.99	6.80	8.63	15.44	31.43
VAMF	WS	10.60	8.55	10.71	19.26	29.86
PGPR	WS	11.52	5.42	8.03	13.45	24.97
VAMF-PGPR	WS	9.10	8.72	10.19	18.91	28.01
Significance:						
Water Level		NS	NS	**	NS	NS
Endophyte		***	**	***	***	**
Endophyte X Water Level		NS	NS	NS	NS	NS

[+] CTR: Control (Non Inoculated)

°VAMF: Vesicular Arbuscular Mycorrhizal Fungi

• PGPR: Plant Growth Promoting Rhizobacteria

WW= Well Watered
WS= Water Stressed
NS= Non significant
*= Significant (0.05)
**= Significant (0.01)
***= Significant (0.001) n=3

Table 4. Effect of VAMF, PGPRs and water level on Growth of *Washingtonia robusta* H. Wendland plants 5 months after inoculation.

Endophyte	**Water Level**	**Plant Height (cm)**	**Leaf Number**	**Root to Shoot Ratio**	**Shoot to Root Ratio**
CTR [+]	WW	53.86	9.29	1.00	1.00
VAMF °	WW	62.57	10.57	0.61	1.63
PGPR •	WW	50.43	9.86	0.74	1.38
VAMF-PGPR	WW	57.57	10.57	0.57	1.76
CTR	WS	49.14	9.43	1.04	0.97
VAMF	WS	57.43	10.43	0.55	1.82
PGPR	WS	54.57	10.00	0.86	1.20
VAMF-PGPR	WS	61.00	11.86	0.48	2.08
Significance:					
Water Level		NS	NS	NS	NS
Endophyte		***	**	***	***
Endophyte X Water Level		**	NS	NS	NS

[+] CTR: Control (Non Inoculated)

°VAMF: Vesicular Arbuscular Mycorrhizal Fungi

• PGPR: Plant Growth Promoting Rhizobacteria

WW= Well Watered

WS= Water Stressed

NS= Non significant

*= Significant (0.05)

**= Significant (0.01)

***= Significant (0.001) n=7

Table 5. Effect of VAMF, PGPRs and water level on Chlorophyll Content of *Washingtonia robusta* H. Wendland plants 5 months after inoculation.

Endophyte	**Water Level**	**Chlorophyll a (mg/L)**	**Chlorophyll b (mg/L)**	**Total Chlorophyll (mg/L)**	**a/b Ratio**
CTR $^{+}$	WW	16.46	7.06	23.52	2.33
VAMF $^{\circ}$	WW	13.92	5.84	19.76	2.37
PGPR $^{\bullet}$	WW	21.41	9.47	30.87	2.27
VAMF-PGPR	WW	19.98	8.74	28.72	2.29
CTR	WS	11.12	5.30	16.41	2.10
VAMF	WS	14.31	6.48	20.78	2.20
PGPR	WS	14.15	6.26	20.41	2.25
VAMF-PGPR	WS	15.11	6.82	21.92	2.22
Significance:					
Water Level		***	***	***	***
Endophyte		**	**	**	NS
Endophyte X Water Level		NS	*	NS	**

$^{+}$CTR: Control (Non Inoculated)
$^{\circ}$VAMF: Vesicular Arbuscular Mycorrhizal Fungi
$^{\bullet}$ PGPR: Plant Growth Promoting Rhizobacteria
WW= Well Watered
WS= Water Stressed
NS= Non significant
*= Significant (0.05)
**= Significant (0.01)
***= Significant (0.001) n=4

Table 6. Effect of VAMF, PGPRs and water level on Carbohydrate Concentration of *Washingtonia robusta* H. Wendland plants 5 months after inoculation.

Endophyte	**Water Level**	**Fructose (μg/g DW)**	**Galactose (μg/g DW)**	**Sucrose (μg/g DW)**	**Trehalose (μg/g DW)**
CTR $^+$	WW	885.76	4.09	3,380.62	2.39
VAMF °	WW	523.37	4.04	3,280.63	1.84
PGPR •	WW	1,306.98	6.15	3,882.73	2.51
VAMF-PGPR	WW	1,036.24	5.56	3,599.83	2.25
CTR	WS	1,225.61	8.45	23,042.23	1.78
VAMF	WS	986.54	6.30	3,070.78	2.16
PGPR	WS	981.66	6.16	2,996.83	1.74
VAMF-PGPR	WS	932.40	6.83	2,892.40	1.48
Significance:					
Water Level		NS	***	***	***
Endophyte		**	**	**	NS
Endophyte X Water Level		***	***	***	**

$^+$CTR: Control (Non Inoculated)
°VAMF: Vesicular Arbuscular Mycorrhizal Fungi
• PGPR: Plant Growth Promoting Rhizobacteria
WW= Well Watered
WS= Water Stressed
NS= Non significant
*= Significant (0.05)
**= Significant (0.01)
***= Significant (0.001) n=4

Table 7. Effect of VAMF, PGPRs and water level on Aminoacid Concentration of *Washingtonia robusta* H. Wendland plants 5 months after inoculation.

Endophyte	**Water Level**	**Alanine (μg/g DW)**	**Valine (μg/g DW)**	**Proline (μg/g DW)**	**Isoleucine (μg/g DW)**	**Serine (μm/g DW)**	**Threonine (μg/g DW)**	**Total Amino acids (μg/g DW)**
CTR [+]	WW	0.35	0.43	0.53	0.35	0.44	0.33	3.08
VAMF [°]	WW	0.49	0.44	0.49	0.36	0.42	0.33	3.18
PGPR [•]	WW	0.48	0.43	0.66	0.35	0.50	0.33	3.42
VAMF-PGPR	WW	0.59	0.44	0.56	0.36	0.46	0.33	3.38
CTR	WS	1.15	6.61	12.12	4.35	1.83	0.82	28.03
VAMF	WS	0.54	3.09	4.11	2.33	0.96	0.65	12.58
PGPR	WS	0.95	4.40	4.99	3.09	1.04	0.60	16.02
VAMF-PGPR	WS	1.01	5.74	6.65	3.74	1.23	0.67	22.52
Significance:								
Water Level		***	***	***	***	***	***	***
Endophyte		NS	**	**	NS	**	**	**
Endophyte X Water Level		NS	**	**	NS	**	**	**

[+] CTR: Control (Non Inoculated)

[°] VAMF: Vesicular Arbuscular Mycorrhizal Fungi

[•] PGPR: Plant Growth Promoting Rhizobacteria

WW= Well Watered
WS= Water Stressed
NS= Non significant
*= Significant (0.05)
**= Significant (0.01)
***= Significant (0.001) n=4