Impact of water deficit on growth, productivity, and water use efficiency in potato (*Solanum tuberosum* L.)

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# Abstract

Drought stress is a serious constraint affecting yields of almost all crops worldwide. The problem is only expected to get worse with water deficits stemming from climate change and population expansion. In this study, we aim to find traits that can help the plants tolerate water deficit without the resultant yield lost, understand the mechanisms of tolerance, and provide useful information for the selection of tolerance in breeding programs. In order to explore the different responses of potato under drought, we have evaluated fifteen genotypes under well watered (WD) and water deficit (WD) conditions for a range of agro-morphological and physiological traits.

Critically, tolerant genotypes such as CIP397077.16, CIP398190.89, and UNICA were able to preferentially put limited water toward tuber production rather than biomass. We also found a lower specific leaf area (SLA) under WD, and that potato genotypes with the ability to maintain high SPAD and low SLA under WD can also maintain high WUE.

**Key words:** abiotic stress, harvest index, lisimeter, drought tolerance

# Introduction

Plant biomass accumulation, and consequently yield, was shown to be inextricably linked to transpiration. The ratio of plant productivity to water loss, water-use efficiency, was very conservative (Sinclair et al., [1984](#ref-sinclair1984WaterUse)).

This ratio is called harvest index (H) and has been found to be relatively stable for a particular cultivar over a fairly wide range of conditions (Donald and Hamblin 1976).

Evans (1980) suggested that one of the main variables for yield increases seen to date has been increases in harvest index.

Evans (1980) further suggested that additional large increases in harvest indices are unlikely. Therefore, further increases in water-use efficiency based on marketable yield are not likely from increasesin the harvest index.

Passioura (1977) and Fischer (1979) have argued that obtaining high harvest indexes underwater-limitedconditions is especially importantin obtaining high water-use efficiencies.

Passioura (1977) proposed that cereals for water-limited environments be developed with roots with restricted water uptake rates. Again, such an alteration would, in principle, conserve water during vegetative growth leaving more soil waterfor extraction during grain development. The key aspect of both strategies is that sustained reproductive growth is essential for a high harvest index.

However, a deeper and more extensive rooting system may have drawbacks. A greater root biomass would almost surely result in lowered harvest index (in potato can be advantage?)

Improved harvest index. As illustrated in equations(7) and(9) improvements in harvest index result directly in increased water-use efficiency. The difficulty is that for many crops it appears that further substantial improvements in harvest index are unlikely.

# Materials and Methods

## Plant material and experimental design

Thirteen potato clones were selected from advanced breeding population collection at International Potato Center (CIP) and two commercial varieties were grown in an environmentally controlled greenhouse at CIP (La Molina Experimental Station) at 28/15°C day/night with 70±5% average relative humidity. The experiment was carried out in complete randomize block design where the first factor was the two irrigation treatments: well-watered (WW), treatment where the moisture was maintained at field capacity and water deficit (WD) and the second factor were compound by the fifteen potato genotypes, Table (2).

## Relationship between transpiration rate and soil water supply

Single plants were grown in a greenhouse in 5 liters plastic pots and It was sown containing 5 kg of dry commercial Sogemix SM2 (75% Peat Moss, perlite, vermiculite, and limestone). Fertilization was done twice with ammonium nitrate; triple superphosphate and potassium sulphate, one before planting mixed with the substrate and the other applied at the surface at 40 days after planting (DAP).

The pots from both well water (WW) and water deficit (WD) treatments were watered to soaking and then allowed to drain overnight. Next day, soil evaporation was minimised by sealed with a plastic bag and all the pots were weighed and it was defined as the initial pot weight. Water deficits were imposed at 45 DAP that coincides with the beginning of the development of the stolons.

Transpiration was calculated by weighing the pots every two days in the between 13:00 and 15:00 hours (GMT -05:00). The transpiration (trs) of each plant was calculated by the procedure previously described by Bhatnagar-Mathur et al. ([2007](#ref-bhatnagar-mathur2007Stressinducible)) and Ray & Sinclair ([1998](#ref-ray1998effect)). The inter-daily transpiration rates of WD plants were normalized against WW plant rates to reduce the influence of day-to-day variation (). The normalization was achieved by dividing transpiration of each individual plant in the WD regime by the mean transpiration of the WW plants. For compare the TRS between plants, a second normalization was done so that the normalized transpiration rate (NTR) of each plant was defined in 1.0 when the soil water content in each pot was at field capacity (Sinclair & Ludlow, [1986](#ref-sinclair1986Influence)). The available soil water or the fraction of transpirable soil water (FTSW), for each pot was calculated by dividing the pot weight minus the final pot weight by the transpirable soil water of that pot ().

## Trait evaluation

### Water use efficiency

Water use efficiency (WUE) is defined as a ratio of biomass accumulation, total crop biomass or crop grain yield, to water consumed, expressed as transpiration, evapotranspiration, or total water input to the system (Sinclair et al., [1984](#ref-sinclair1984WaterUse)). According to this concept we calculated the biomas water use efficency (wue) and tuber water use efficency (TWUE). The WUE was calculated as the total biomass in dry weight produced divided by the cumulative water transpired (Dalla Costa et al., [1997](#ref-dallacosta1997Yield)) and for TWUE was used the dry weight from tuber production divide the cumulative water transpired during the treatment.

### Water components

The relative water conten (RWC) was determined by weighing the third leaflet (FW) from the third leaf from the apical part from the youngest fully expanded leaf of each plant. Each leaflet were placing in a 4x3 inch ziploc bag containing distilled water for 24 hours and after these time it was removed to taking turgid weight (TW) afterwards it was dried in an oven at 90 ºC for 24 hours and weighed (DW). The RWC was calculated according to Vasquez-Robinet et al. ([2008](#ref-vasquez-robinet2008Physiological)) by the formula .

Leaf osmotic potential (LOP) was determined using a dew point microvoltmeter (HR-33T Wescor Inc., Logan, UT, USA) with leaf discs of 5 mm diameter, taken from the third fully extended leaf. The leaf discs were put in 1 ml cryogenic tubes and frozen in liquid nitrogen for further analysis. The frozen leaves were incubated at 22°C for 30 min in a sealed C-52 chamber (Wescor Inc., Logan, UT, USA). The total osmotic adjustment (TOA) was defined as the difference in LOP between the WW and the WD plants (Hessini et al., [2009](#ref-hessini2009Effect)).

## Chlorophyll content (SPAD)

The chlorophyll content of the plant was evaluated by taking SPAD measurements using a SPAD-502 chlorophyll meter (Konica Minolta Sensing, Inc., Osaka, Japan) from the third youngest fully expanded leaf from three points (upper, middle and lower leaflet of a leaf). Individual readings of leaflets were averaged to represent individual measurement of a leaf. The evaluations were done on light adapted leaves at 29, 59, 76, and 83 DAP.

## Post-harvest traits and indices

The harvest was at 90 DAP. The plants were separated in four components: leaves, stems, roots and tubers. The dry weight (g) components were determined by drying them at 80°C for 3 days in a forced air oven: leaf (LDW), stem (SDW), root (RWD), tuber (TDW). The leaf area (LFA) of the plants was measured in cm2 by taking photographs of all the leaves arranged on a wooden board and analyzing the pictures using SisCob v1.0 (EMBRAPA Instrumentação Agropecuária, 2003).

The tolerance to decrease of water supply (TDWS) or the percentage of yield reduction was the index used to evaluated the drougth tolerance and it is used to characterize the response of each genotype to WD (Deblonde et al., [1999](#ref-deblonde1999Responses); Lahlou et al., [2003](#ref-lahlou2003effect)). To calculate TDWS the TDW in WD treatment for every genotype was expressed relative to its TDW in the WW treatment. The harvest index (HI) was calculated as the ratio of TDW related to the total dry biomass (TDB) and specific leaf area (SLA) was calculated by dividing the LFA with LDW.

## Statistical analysis

The experiment was carried out in a complete randomize block design with two factros; the irrigation with well water (WW) and water deficit (WD) treatments and fifteen potato genotypes. Each treatment consisted of five replicates with one potato plant for each experimental unit. Statistical analysis and graphs were performed in the statistical software R (Lozano Isla et al., [2020](#ref-R-GerminaR); R Core Team, [2020](#ref-R-base)). The analysis of variance (ANOVA) was performed to evaluate the differences between the factors and the comparison of the means with the Student-Newman-Keuls test (p<0.05) from agricoale package (de Mendiburu, [2020](#ref-R-agricolae)). For the multivariate analysis correlation analysis was performed (**???**; de Mendiburu, [2020](#ref-R-agricolae)) and principal components analysis were made with FactoMineR package (Husson et al., [2020](#ref-R-FactoMineR)).

# Result

## Treatment application

## Traits evaluation

## Multivariate analysis

## Multiselection index

# Dicussion

# Conclusions

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# References

Bhatnagar-Mathur, P., Devi, M. J., Reddy, D. S., Lavanya, M., Vadez, V., Serraj, R., Yamaguchi-Shinozaki, K., & Sharma, K. K. (2007). Stress-inducible expression of At DREB1A in transgenic peanut (Arachis hypogaea L.) Increases transpiration efficiency under water-limiting conditions. *Plant Cell Reports*, *26*(12), 2071–2082. <https://doi.org/10.1007/s00299-007-0406-8>

Dalla Costa, L., Delle Vedove, G., Gianquinto, G., Giovanardi, R., & Peressotti, A. (1997). Yield, water use efficiency and nitrogen uptake in potato: Influence of drought stress. *Potato Research*, *40*(1), 19–34. <https://doi.org/10.1007/BF02407559>

Deblonde, P. M. K., Haverkort, A. J., & Ledent, J. F. (1999). Responses of early and late potato cultivars to moderate drought conditions: Agronomic parameters and carbon isotope discrimination. *European Journal of Agronomy*, *11*(2), 91–105. <https://doi.org/10.1016/S1161-0301(99)00019-2>

de Mendiburu, F. (2020). *Agricolae: Statistical procedures for agricultural research*. <https://CRAN.R-project.org/package=agricolae>

Hessini, K., Martínez, J. P., Gandour, M., Albouchi, A., Soltani, A., & Abdelly, C. (2009). Effect of water stress on growth, osmotic adjustment, cell wall elasticity and water-use efficiency in Spartina alterniflora. *Environmental and Experimental Botany*, *67*(2), 312–319. <https://doi.org/10.1016/j.envexpbot.2009.06.010>

Husson, F., Josse, J., Le, S., & Mazet, J. (2020). *FactoMineR: Multivariate exploratory data analysis and data mining*. <https://CRAN.R-project.org/package=FactoMineR>

Lahlou, O., Ouattar, S., & Ledent, J.-F. (2003). The effect of drought and cultivar on growth parameters, yield and yield components of potato. *Agronomie*, *23*(3), 257–268. <https://doi.org/10.1051/agro:2002089>

Lozano Isla, F., Benites Alfaro, O., & Pompelli, M. F. (2020). *GerminaR: Indices and graphics for assess seed germination process*. <https://flavjack.github.io/germinaquant/>

Ray, J. D., & Sinclair, T. R. (1998). The effect of pot size on growth and transpiration of maize and soybean during water deficit stress. *Journal of Experimental Botany*, *49*(325), 1381–1386. <https://doi.org/10.1093/jxb/49.325.1381>

R Core Team. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>

Sinclair, T., & Ludlow, M. (1986). Influence of Soil Water Supply on the Plant Water Balance of Four Tropical Grain Legumes. *Australian Journal of Plant Physiology*, *13*(3), 329. <https://doi.org/10.1071/PP9860329>

Sinclair, T. R., Tanner, C. B., & Bennett, J. M. (1984). Water-Use Efficiency in Crop Production. *BioScience*, *34*(1), 36–40. <https://doi.org/10.2307/1309424>

Vasquez-Robinet, C., Mane, S. P., Ulanov, A. V., Watkinson, J. I., Stromberg, V. K., De Koeyer, D., Schafleitner, R., Willmot, D. B., Bonierbale, M., Bohnert, H. J., & Grene, R. (2008). Physiological and molecular adaptations to drought in Andean potato genotypes. *Journal of Experimental Botany*, *59*(8), 2109–2123. <https://doi.org/10.1093/jxb/ern073>

# Tables

Table 1: List of abbreviations

|  |  |
| --- | --- |
| Variable | Abbreviation |
| Soil Plant Analysis Development | SPAD |
| Height | HGT |
| Relative water content | RWC |
| Leaf osmotic potential | LOP |
| Leaf dry weight | LDW |
| Stem dry weight | SDW |
| Root dry weight | RDW |
| Tuber dry weight | TDW |
| Tuber number | NTUB |
| Total transpiration | TRS |
| Leaf area | LFA |
| Total dry biomass | TDB |
| Harvest index | HI |
| Specif leaf area | SLA |
| Water use efficiency | WUE |
| Tuber water use efficiency | TWUE |

Table 2: Potatos (*Solanum tuberosum* L.) genotypes used for water deficit experiment with 13 lines from advanced breeding population at International Potato Center (CIP) and two comercial varieties.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Number | Genotypes | Adaptability | Growning period | Heat tolerance | Dry matter (%) |
| G01 | CIP720088 |  | early |  | 19 |
| G02 | CIP392797.22 | Lowland and highland Tropics | Medium |  | 21 |
| G03 | CIP397077.16 | Lowland tropics | Medium |  | 20 |
| G04 | CIP398192.213 | Mid elevation tropics | Medium | Tolerant | 22 |
| G05 | CIP398180.612 |  | Medium |  |  |
| G06 | CIP398208.704 | Mid elevation tropics | Medium | Tolerant | 24 |
| G07 | CIP398098.119 | Mid elevation tropics | Medium | Tolerant | 26 |
| G08 | CIP398190.89 | Mid elevation tropics | Medium | Tolerant | 21 |
| G09 | CIP398192.592 | Mid elevation tropics | Medium | Tolerant | 21 |
| G10 | CIP398201.510 | Mid elevation tropics | Medium | Tolerant | 20 |
| G11 | CIP398203.244 | Mid elevation tropics | Medium | Tolerant | 20 |
| G12 | CIP398203.5 | Mid elevation tropics | Medium | Tolerant | 13 |
| G13 | CIP398208.219 | Mid elevation tropics | Medium | Tolerant | 22 |
| G14 | CIP398208.33 | Mid elevation tropics | Medium | Tolerant | 21 |
| G15 | CIP398208.620 | Mid elevation tropics | Medium | Tolerant | 21 |

Summary descriptives table by groups of `treat’

|  | **WD** | **WW** | **p.overall** |
| --- | --- | --- | --- |
|  | ***N=75*** | ***N=75*** |  |
| spad\_29 | 56.1 (4.92) | 56.7 (4.98) | 0.470 |
| spad\_59 | 47.9 (4.36) | 45.8 (3.66) | 0.001 |
| spad\_76 | 46.0 (5.44) | 41.7 (3.61) | <0.001 |
| spad\_83 | 44.1 (5.92) | 39.7 (4.52) | <0.001 |
| hgt | 132 (15.3) | 150 (15.8) | <0.001 |
| rwc | 57.9 (6.09) | 69.0 (5.33) | <0.001 |
| lop | -2.84 (0.30) | -2.25 (0.29) | <0.001 |
| ldw | 12.0 (3.68) | 17.3 (5.55) | <0.001 |
| sdw | 11.6 (9.06) | 14.5 (6.10) | 0.020 |
| rdw | 3.67 (1.94) | 3.50 (1.96) | 0.588 |
| tdw | 23.7 (10.8) | 39.8 (19.0) | <0.001 |
| ntub | 12.0 (6.21) | 12.0 (4.94) | 0.976 |
| trs | 4.52 (1.22) | 7.85 (2.20) | <0.001 |
| lfa | 2488 (797) | 7100 (2380) | <0.001 |
| rdl | 33.1 (6.45) | 32.5 (5.81) | 0.528 |
| tdb | 50.8 (15.7) | 74.7 (24.1) | <0.001 |
| hi | 0.47 (0.16) | 0.53 (0.14) | 0.016 |
| sla | 218 (62.0) | 415 (81.8) | <0.001 |
| wue | 11.3 (2.15) | 9.53 (1.26) | <0.001 |
| twue | 5.31 (2.03) | 5.09 (1.75) | 0.493 |

# Figures

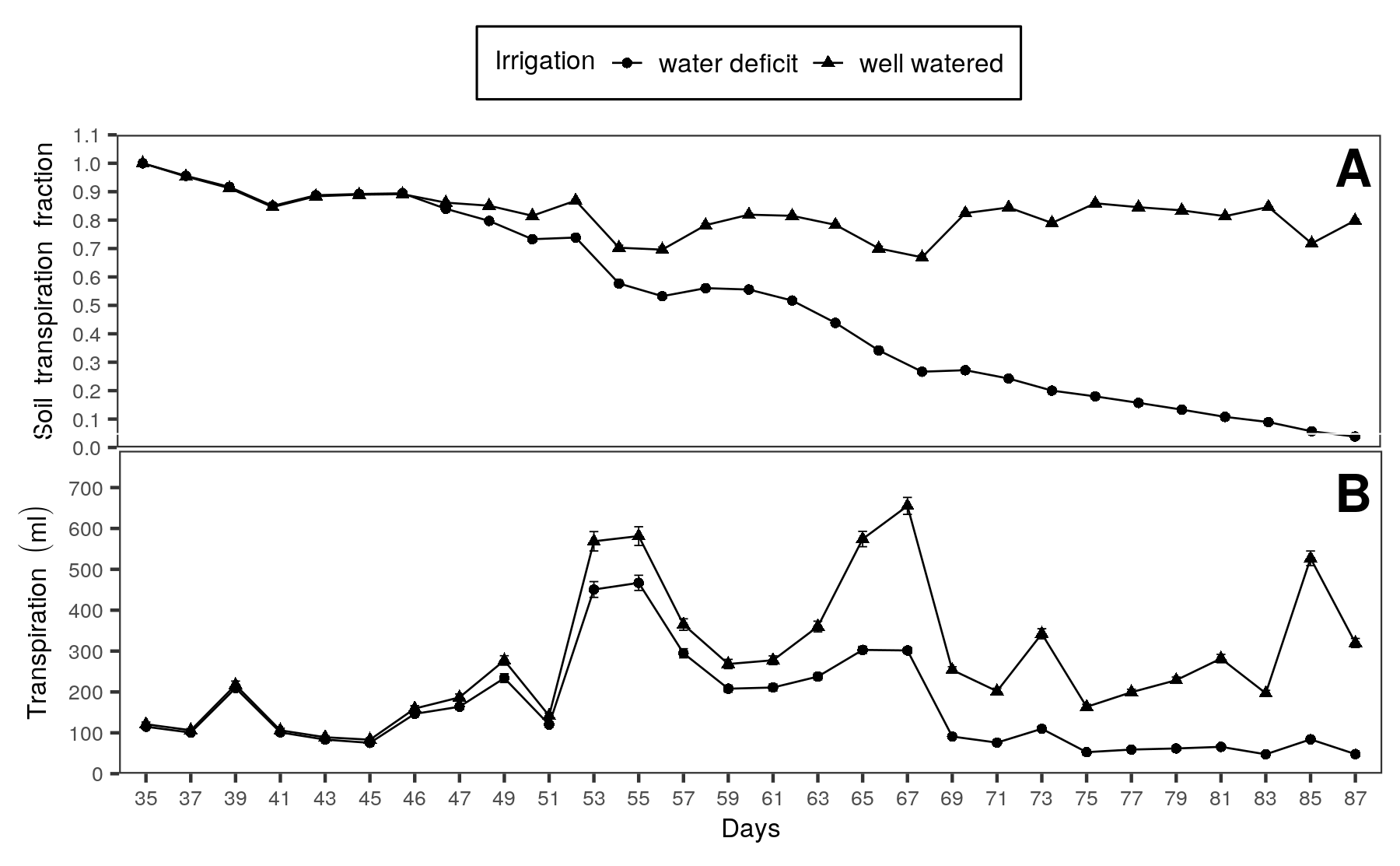


Figure 1: Soil transpiration fraction and transpiration during the experiment

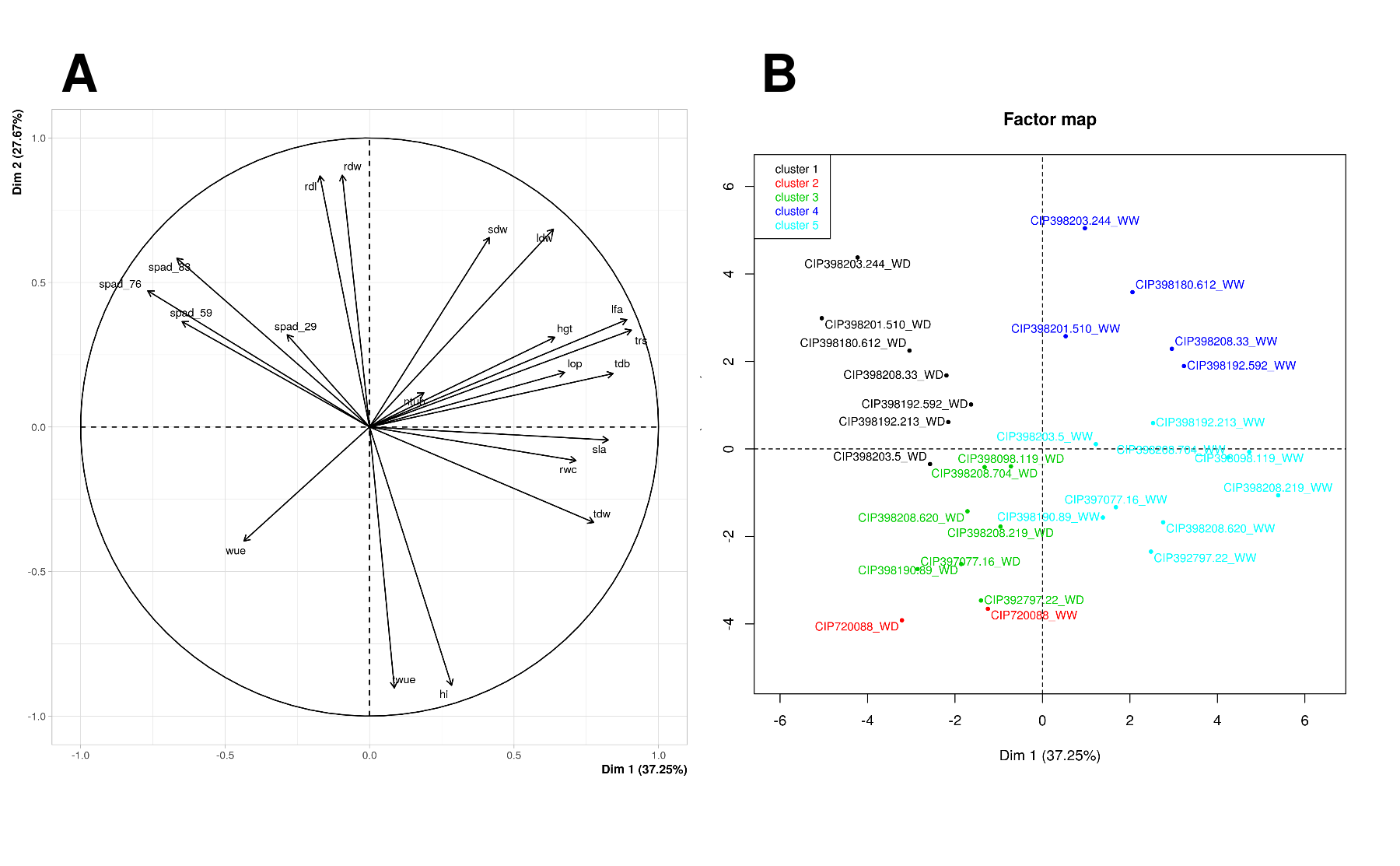


Figure 2: Principal component analysis

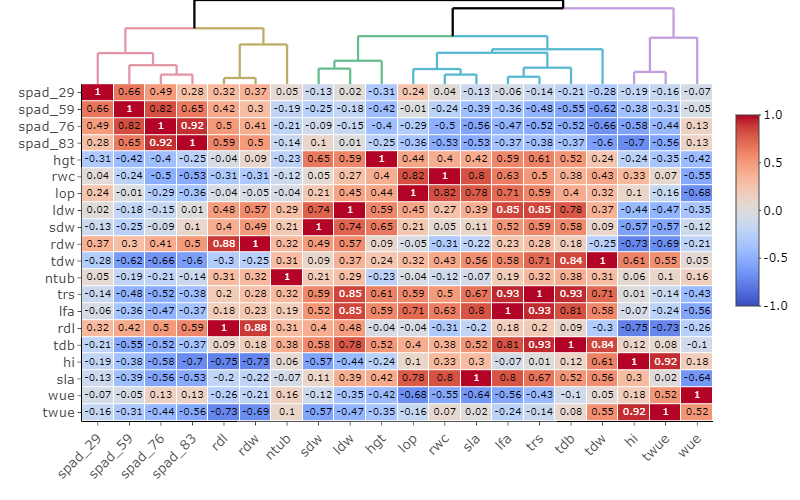


Figure 3: Correlation analysis