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RESEARCH

The impact of fertilizing *Swietenia mahagoni* (L.) Jacq. seedlings under water stress with various nitrogen and phosphorous sources

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Background: Drought represents a significant global threat, affecting agricultural productivity and leading to water shortages. Nitrogen (N) and phosphorus (P) are essential macronutrients that promote plant growth and enhance tolerance to drought. *Swietenia mahagoni* (L.) Jacq. (mahogany), is a high-quality timber species recognized for its extensive commercial and pharmaceutical applications. The present study aims to study the effect of fertilization by different forms of N and P on the growth and drought tolerance of mahogany seedlings.
Results: The application of three levels of soil water regime (100%, 75%, and 50%, field capacity [FC]) on mahogany seedlings, with different combinations of N fertilizers (ammonium sulfate [AS], ammonium nitrate [AN], and urea [UR]) and P (phosphoric acid [PA], superphosphate [SP], and triple superphosphate [TS]) in two seasons, indicating that the water regimes and all the combinations of N and P forms significantly increased mahogany growth (number of leaves, root length, stem height, the fresh and dry weights of shoots, roots, stem, and leaves), water use efficiency (WUE), and N and P leaves content. The highest values were obtained from irrigation with 100% FC, while the lowest was from 50% FC. All combinations of N and P significantly enhance all growth parameters compared to the control. Furthermore, AS, PA, and AS-PA had significantly the highest values of all studied characteristics. While AN, SP, and AN-TS had the lowest values. The interaction between different water regimes and different N and P combinations had a highly significant ($p \leq 0.001$) effect on WUE, root length, leaves dry weight, and N leaf content in both growing seasons. While fresh and dry weights of stem and shoots were significant at $p \leq 0.05$ in the second growing season.
Conclusions: Drought stress had a negative impact on all vegetative characteristics, WUE, and N and P leaves content of mahogany seedlings. All the combinations of N and P significantly improved growth characteristics under drought conditions, but the most effective treatments were AS, PA, and AS-TS. The present study is very important in that it provides critical insights for enhancing drought adaptation, reducing water usage, and enhancing plant growth characteristics.

Keywords: drought, field capacity, mahogany, nitrogen, phosphorus nutrients, water stress

Introduction

Water resources are one of the century's very important economic and social problems (Abd Ellah 2020). Water scarcity and climate change in many arid and semiarid countries have agricultural scientists working hard to develop practical solutions to the country's economic issues. These include developing novel types that can withstand harsh temperatures and water shortages, as well as generating nutrients that increase plant tolerance to any severe environmental conditions (Ghazi et al. 2023). Drought stress is the most serious abiotic threat to plant development and productivity around the world, particularly in arid and semiarid environments (Ahmad et al. 2015), and any modifications in water irrigation levels could reduce crop production (Kang et al. 2024).

Egypt will face significant obstacles and limitations in its water resources due to its fixed supply of Nile water. In 2019, Egypt's annual resource-to-needs imbalance was around 21×10^9. Additionally, it is anticipated that 34×10^9 m^3 of water will be required to ensure food security through virtual water supplies; by 2050, this disparity will increase even more, prompting institutions at all levels to heavily rely on non-traditional water sources (Elkholy 2021).

Water was essential for the germination process, cell division and enlargement, metabolic activity, and other vital processes (da Silva et al. 2013). Fertilizer and irrigation are two of the majority of important factors determining tree enlargement. Even fertilized soil may face nutritional deficiencies due to a lack amount of moisture (da Silva et al. 2011). Drought conditions have an impact on the mobility and loss of both nitrogen (N) and phosphorus (P) nutrients and their availability for plants (Homyak et al. 2017).

Concerning soil types in Egypt, P supply is recognized as one of the greatest critical growth factors for developing plants. Because P quickly turns to an unsolved state for plant absorption due to its reactivity with soil mineral components (Dawa et al. 2007). Cultivated soils require a considerably large amount of P fertilizers to fulfill plant supplies (Khan et al. 2023). The majority of Egypt's soils are alkaline, with a pH of 7 to 9 (El-Ramady et al. 2019). Alkaline soils are deficient in both N and P and as a result, the production of plants in these soils is significantly lower than usual (Adnan et al. 2018). The high soil pH (8–9) lowers P movement and diffusion, making P less available to plants (Sardans et al. 2004). Plants' ability to uptake P is much related to soil pH, with the largest solubility and availability of P at pH 6.5 and lowering as the pH rises into the alkaline range due to the development of low-solvent calcium phosphate components (Hopkins and Ellsworth 2005).

In Egypt, superphosphate (SP) nutrition has been the primary source of phosphate fertilizer for agriculture. However, new methods have lately emerged, such as phosphoric acid (PA), which is routinely supplied directly via the water during the irrigation process, particularly in alkaline and calcareous soils (Akhtar et al. 2016). SP is 90% dissolved in water, but because of its low P content, it is not widely applied. To increase the P concentration of SP, triple superphosphate (TS), or concentrated SP, is created by reacting rock phosphates with PA (Marschner 1995). Furthermore, a widely-applied phosphate fertilizer is TS (Rosen et al. 2014). PA represents a liquid fertilizer that was used to give phosphatic fertilizers (Quader 2010). The use of liquid P fertilizers with soil acidification could not only increase crop yield in salt-affected soils but also improve them by minimizing their pH (Hussain et al. 2011).

N and P could help plant tolerance to shortages of water by improving the functions of the photosynthetic system and antioxidant enzymes (Gelaw et al. 2023). The unavailability of P in the soil is the greatest challenge for crop productivity, especially after plants suffer from abiotic stresses such as drought (Khan et al. 2023). P is a vital part of nucleic acids, phospholipids, high-energy phosphate bond complexes, and numerous coenzymes (Wyngaard et al. 2016). Also, P is a basic component of the cellular function of plants and helps various vital processes in the plant, including early root and seedling growth, seed formation, standardized maturity and quality, winter hardiness, and water use efficiency (WUE) (Taiz et al. 2015). P is a vital part of ATP, the molecule that supplies energy to the plant for feeding transfers, absorption of nutrients, and respiration. It improves the quality of the crop, encourages early maturation, and enhances the resistance to diseases (Khan et al. 2014).

Plants include N in proteins, enzymes, nucleic acids, amino acid sequences, chlorophyll, and other important chemicals. As a result, N plays an important role in plant development and growth, including cell division, photosynthesis, and energy transmission. Nutritional combinations are sometimes more effective than individual nutrients, and interactions can be helpful or toxic (Khan et al. 2014). In Egypt, the most chemical N forms as commercial fertilizers are ammonium nitrate (AN), urea (UR), and ammonium sulfate (AS). Those three types of chemical N fertilizer forms are increasing plant growth and productivity due to their quick and easy availability to the root plant system (Metwaly 2018).

Swietenia mahagoni (L.) Jacq. belonged to the Meliaceae family and has commercial and medicinal importance (Divya et al. 2012). It is known as American mahogany, native to the southeastern United States. It is an afforestation plant, that needs 25 years to mature, a mature tree can be 15 to 20 m high on average, and a maximum of 25 m high (Orwa et al. 2009). Some common names for mahoganies are Spanish, Cuban, Small-leaved, and West Indian mahoganies (Gilman and Watson 2019). It is a large semi-evergreen wood tree with a rounded canopy endemic to South Florida, the Bahamas, and the western Caribbean. It is a sturdy, fast-growing tree with dense wood. It is highly resistant to wind damage and serves well as a shade or road tree (Sukardiman and Ervina 2020). Additionally, it has a fantastic canopy structure, making it a great ornamental landscape tree. Spanish mahogany is used in shipbuilding and furniture manufacturing, it is used commonly for high-quality furniture, joinery, musical instruments, etc. It is very expensive due to its timber quality, color, stiffness, and durability. It is used in many developing countries with natural diversity resources (Sukardiman and Ervina 2020).

It is used also for a medical purpose providing vitamins and iron (Hossain 2015). Seeds oil was used as a pesticide, while seeds were used as an antidiabetic factor that reduces blood glucose levels (Sukardiman and Ervina 2020) and gestational diabetes mellitus (Khotimah et al. 2024). The bark of the Spanish mahogany tree is an astringent that is used to treat diarrhea, as a source of iron and vitamins, and to cause bleeding. In the event of tuberculosis, the bark can be used to clear blood, improve appetite, and recover vigor (Hossain 2015). It is used to treat fever, anemia, hypertension, dysentery, amoebiasis, chest pains, malaria, cancer, depurative, and intestinal parasitism (Maiti et al. 2007). The leaf soup is used to treat nervous problems, the seed infusion to treat chest pain, and a leaf or root poultice to treat bleeding (Divya et al. 2012). In addition, studies indicated that its seed extract has antidiabetic, antibacterial activities, anti-oxidative and anti-hyperlipidemia activities (Sahgal et al. 2009), also, anti-fungal activity (Sahgal et al. 2011), anti-tumor activity (Ghosh et al. 2009), and its leaf extract has anti-ulcer activity (Al-Radahe et al. 2013). Its seed and bark are used for curing Psoriasis, Diabetes, and Diarrhea, and also is used as an antiseptic in cuts and wounds (Haldar et al. 2011).

The present study aims to study the effect of fertilization with different forms of N and P sources on the growth and drought tolerance of mahogany seedlings to obtain their highest growth using the lowest available water resources.

Materials and Methods

Preparation of experiment

The experiment occurred in the natural conditions of Gemmeiza Agricultural Research Station, in the Middle of the Nile Delta, Egypt (Lat. 30.97 N and Long. 30.97 E), through the two seasons (2022–2023) and (2023–2024). Timber seedlings of mahogany trees were used. Its seedlings with 11–13 leaves and 35–40 cm height were bought from the Timber Trees and Forestry Research Department nursery, Horticulture Research Institute, and Agricultural Research Center. In half of May, seedlings were cultivated in natural environmental conditions (Table S1), transferred at the age of about one year, and uniform seedlings (selected based on height, stem diameter, and number of leaves) were transplanted individually in black plastic bags (a depth of 45 cm and a diameter of 18 cm) filled with a mixture of 9.0 kg air-dried soil as soil and sand at a 3:1 ratio. The experimental soil was analyzed, and its physical and chemical characteristics are found in Table S2 according to the standard procedures of Jackson (2005).

Experimental design and treatments

A split-split-plot design experiment was used to investigate the impact of N and P nutrition on seedlings of Mahogany growth under drought conditions. The main plot involved three irrigation regime factors (100% control, 75%, and 50% field capacity [FC]), and a mixture of both N (UR, AN, and AS) and P (SP, PA, TS) nutrition forms were represented sub-plots, while the means of N and P forms were represented sub-sub-plots, and the plots were distributed in a completely randomized design with three replications; each replicate involved ninety seedlings and thirty applications (Table S3). Recommended nutrition rates of N and P were applied as chemical fertilizer forms.

Water regime treatments

Before the beginning of the experiment, the gravimetric method was used to estimate the soil water content according to the standard procedures of Reynolds (1970), and irrigation level applications were performed by weighting plastic bags every 3 days and adding the required amount of water in the whole period of the study to obtain the percentage of FC to every application. The irrigation rates are expressed as 100% (3.5 L, well), 75% (2.62 L, mild), and 50% (1.75 L, severe) FC. These three forms of irrigation regime were applied in the half of July in both seasons and by using tap water in the irrigation of seedlings, according to the standard procedures of Jackson (1973). Chemical analysis of irrigation tap water is represented in Table S4.

Nutrition treatments

Three P forms (PA, SP, and TS) were applied once as a basal dose before the cultivation process, while PA was added once with irrigation water after one month of the cultivation process at a rate of 2.6 g of P_2O_5, TS (46%) = 5.65 g, SP (12.5%) = 20.8 g, and PA (H_3PO_4 55.33%) contained density (1.596 g/cm^3) and P_2O_5% (40.05 w/w) = 41 cm L^{-1} (PA). Also, three N forms (AS, AN, and UR) were applied in three split doses through the half of July, August, and September at a rate of 2 g of N as AN (33.5%) = 6 g, UR (46%) = 4.3 g, AS (20.2%) = 9.6 g, and untreated plants as control. Until the irrigation regime started, all cultivated seedlings were irrigated regularly, and the study was continued for one year in both seasons.

Vegetative growth measurements

At the end of the experimental study, vegetative growth features (stem height (cm), length of the main root (cm), number of leaves, fresh and dry weights of shoots, roots, stems, and leaves (g)) were determined. The fresh weight of each shoot, root, stem, and leaf was determined by weighing each part individually (g). Fractions of the whole fresh plant were air-dried and oven-dried at 70°C till a steady weight, then the dry weight of each part (roots, stems, and leaves) was recorded.

WUE was determined according to Bacon (2009) using the formula:

WUE = Total biomass (g) / Water consumption (L)

Where the total biomass of seedlings is equal to the total fresh weight of their roots, stem, and leaves at the end. Water quantities supplied were estimated by calculating the total amounts of irrigation water provided to seedlings at different irrigation levels (FC) throughout the growing season.

N and P content of leaves

For the estimation of N and P contents in leaves, the samples of fresh leaves were taken, washed with tap and distilled water, dried at 80°C, milled, and subsequently digested with concentrated H_2SO_4 and H_2O_2. N% were estimated using the micro-Kjeldahl method (Liang and MacKenzie 1994). The total P content was estimated by using the molybdate-blue colorimetric method as mentioned by Kitson and Mellon (1944).

Statistical analysis

After the end of the research, the collected data were subjected to the statistical analysis of variance (ANOVA) by using the CO-STAT computer package program to test the significance difference. Duncan's test at 5% probability was used to compare the differences among treatment means (Stern 1991). Two-way ANOVA was applied to indicate the significance of the interaction between different drought conditions and different P and N fertilizer sources.

Results

Influencing of water regime

The results in Table 1 indicated that drought condition levels significantly negatively influenced the seedlings, leading to a decrease in the number of leaves, stem height, and fresh and dry weights of leaves. The highest data were observed in seedlings irrigated at 100% FC, with stem height (98.50 and 98.65 cm), leave number (48.00) leaves fresh (58.77 and 59.34 g), and dry weights (40.47 and 41.06 g) in both seasons, respectively.

Also, It is noticed that, by increasing levels of water deficit, fresh and dry weights of stem and shoot were significantly decreased, as the smallest value was obtained from 50% FC; declined by 14.4% and 18.23%, respectively in the first season and by 14.3% and 16.4%, respectively in the second season (Table 2). Fresh weight of shoots declined by 16.74% and 16.41% in the first and second seasons, respectively and dry weights declined by 22.4% and 21.6% in the first and second seasons, respectively. While the highest values were obtained from 100% FC.

In addition, drought stress had a significantly negative impact on fresh and dry weights of roots (Table 3). The highest results were obtained at 100% FC. On the other hand, the lowest values were noticed at 50% FC, which declined by 9.72% and 16.8%, respectively compared with control in the 1st season, and 9.53% and 15.93%, respectively in the 2nd season. While root length was increased by 12.6 % at 50% FC compared to control. Plant WUE had the highest values at 50% FC, it was increased by 41.1% and 41.3% in the first and second growing seasons, respectively.

Influence of N and P nutrition

All nutrition with N and P forms had a positive influence and increased all studied traits (stem height, number of leaves, fresh and dry weights of shoots, roots, stems, and leaves, N and P content in the leaves, root length, and WUE) compared to the control. There are significant variations among the diversity of nutrition with N and P forms. The nutrition with AS-PA had significantly the highest value of mahogany seedling traits (Table 1). The nutrition with AS-PA increased leaves number by 30.9% and 35.7%, stem height by 27.0% and 29.2%, fresh weight of leaves by 44.17% and 46.96%, and dry weight of leaves by 61.63% and 61.55%, in the first and second season, respectively compared with control.

Also, AS-PA nutrition enhances the fresh weight of the stem by 35.93% and 37.84%, stem dry weight by 44.4% and 47.34%, shoot fresh weight by 39.22% and 41.5%, shoot dry weight by 50.8% and 52.64% in the first and second seasons, respectively compared with control (Table 2). Furthermore, it enhanced the root fresh weight by 35.3% and 39.25%, root dry weight by 46.5% and 51.9%, root length by 39.23% and 42.55%, and WUE by 39.03% and 41.75% in the first and second season, respectively compared with control (Table 3). The highest value of AS-PA treatment was obtained at 100% FC except for root length, while the lowest values of all studied characteristics were obtained at 50% FC in the first and second seasons.

In addition, N and P contents of leaves significantly increased by the nutrition of different combinations of N and P fertilizers under water stress (Table 4). The combination of AS-PA led to the enhancement of leaves N content by 27.5% and 35.16% and leaves P content by 51.4% and 57.58% in the first and second seasons, respectively. The highest value of AS-PA was obtained at 100% FC, while the lowest values of them were obtained at 50% FC in the first and second seasons. The interactions between different water regimes and different fertilizer combinations had a highly significant ($p \leq 0.001$) effect on the N and P contents of leaves (Table 4).

By comparing the effect of the mean fertilization with N forms, AS fertilizer had significantly the highest value of all studied characteristics, while the lowest was obtained from AN fertilizer in the first and second seasons (Figs. 1-4) with the highest value at 100% FC and the lowest value at 50% FC. While the mean fertilization with P forms, PA had significantly the highest value of all studied characteristics, while the lowest values were obtained from SP in the first and second seasons, with the highest value at 100% FC and the lowest value at 50% FC.

Table 1 Different vegetative characteristics of *Swietenia mahagoni* (L.) Jacq. as influenced by N and P forms under different water regimes

Nutritious \ Drought	1st season 100% FC	1st season 75% FC	1st season 50% FC	1st season Mean	2nd season 100% FC	2nd season 75% FC	2nd season 50% FC	2nd season Mean
Leaves number								
Control	40.00^{lmn}	38.00^{mno}	35.00^{o}	38.00^{i}	38.00^{o}	37.00^{o}	34.00^{p}	36.00^{g}
UR-SP	46.00^{ghi}	44.00^{ijk}	41.00^{klm}	44.00^{f}	46.00^{hij}	45.00^{ijk}	41.00^{mn}	44.00^{e}
UR-TS	47.00^{fghi}	45.00^{hij}	42.00^{jkl}	45.00^{f}	47.00^{ghi}	46.00^{hij}	42.00^{lm}	45.00^{e}
UR-PA	55.00^{ab}	53.00^{bc}	50.00^{cdef}	53.00^{b}	56.00^{ab}	54.00^{bc}	51.00^{de}	54.00^{b}
AN-SP	42.00^{jkl}	40.00^{lmn}	37.00^{no}	40.00^{h}	43.00^{klm}	41.00^{mn}	38.00^{o}	41.00^{f}
AN-TS	44.00^{ijk}	42.00^{jkl}	39.00^{lmn}	42.00^{g}	44.00^{jkl}	42.00^{lm}	39.00^{no}	42.00^{f}
AN-PA	53.00^{bc}	51.00^{cde}	48.00^{efgh}	51.00^{c}	54.00^{bc}	52.00^{cd}	49.00^{efg}	52.00^{c}
AS-SP	49.00^{defg}	47.00^{fghi}	44.00^{ijk}	47.00^{e}	50.00^{def}	48.00^{fgh}	45.00^{ijk}	48.00^{d}
AS-TS	51.00^{cde}	49.00^{defg}	46.00^{ghi}	49.00^{d}	51.00^{def}	49.00^{efg}	46.00^{hij}	49.00^{d}
AS-PA	57.00^{a}	55.00^{ab}	52.00^{bcd}	55.00^{a}	56.00^{ab}	57.00^{a}	54.00^{bc}	56.00^{a}
Mean	48.00^{a}	46.00^{b}	43.00^{c}		48.00^{a}	47.00^{b}	44.00^{c}	
$F_{water\ regimes\ x\ fertilizers}$ = 8.62930^{ns}					$F_{water\ regimes\ x\ fertilizers}$ = 0.4458509^{ns}			
Stem height (cm)								
Control	82.65^{qr}	79.06st	70.48^{u}	77.40^{j}	80.27^{mn}	78.60^{n}	68.11^{o}	75.66^{i}
UR-SP	95.19^{hij}	90.96^{klm}	82.86^{qr}	89.67^{g}	96.00^{g}	92.37^{hi}	84.45^{l}	90.94^{f}
UR-TS	97.14^{fgh}	93.48^{ijk}	85.16^{pq}	91.93^{f}	96.83^{fg}	93.10^{h}	85.57^{l}	91.83^{f}
UR-PA	108.20^{b}	103.94^{c}	98.67^{efg}	103.60^{b}	108.80^{b}	104.80^{c}	99.98^{de}	104.53^{b}
AN-SP	90.13^{lmn}	86.40^{op}	78.21^{t}	84.91^{i}	91.03^{hij}	87.90^{k}	78.90^{n}	85.94^{h}
AN-TS	93.53^{ijk}	88.84^{mno}	81.67^{rs}	88.01^{h}	93.23^{h}	89.07^{jk}	81.82^{m}	88.04^{g}
AN-PA	104.10^{c}	100.52^{de}	92.61^{jkl}	99.08^{c}	105.70^{c}	101.61^{d}	93.22^{h}	100.17^{c}
AS-SP	100.30^{de}	96.12^{ghi}	87.90^{nop}	94.77^{e}	100.87^{d}	97.18^{fg}	88.88^{jk}	95.64^{e}
AS-TS	102.47^{cd}	98.48^{efg}	90.27^{lmn}	97.07^{d}	101.80^{d}	98.55^{ef}	90.41^{ij}	96.92^{d}
AS-PA	111.28^{a}	107.22^{b}	99.73^{def}	106.07^{a}	112.00^{a}	108.37^{b}	100.22^{de}	106.86^{a}
Mean	98.50^{a}	94.50^{b}	86.76^{c}		98.65^{a}	95.15^{b}	87.16^{c}	
$F_{water\ regimes\ x\ fertilizers}$ = 0.3278721^{ns}					$F_{water\ regimes\ x\ fertilizers}$ = 0.8363272^{ns}			
Leaves fresh weight (g plant^{-1})								
Control	41.21^{nop}	37.63^{p}	29.30^{q}	36.05^{g}	40.18^{r}	36.33^{s}	27.68^{t}	34.73^{i}
UR-SP	55.97^{efg}	50.17^{ijk}	44.67^{mn}	50.27^{e}	56.39^{hi}	51.47^{lm}	45.37^{p}	51.08^{f}
UR-TS	58.38^{de}	51.91^{hij}	46.33^{klm}	52.21^{e}	58.68^{efg}	52.23^{klm}	46.61^{op}	52.51^{e}
UR-PA	67.23^{ab}	61.20^{cd}	55.83^{efgh}	61.42^{b}	68.20^{b}	62.05^{d}	56.90^{gh}	62.38^{b}
AN-SP	52.20^{ghij}	46.07^{lm}	40.17^{op}	46.15^{f}	53.21^{jkl}	47.44^{o}	41.39^{qr}	47.35^{h}
AN-TS	53.88^{fghi}	47.99^{klm}	42.13^{no}	48.00^{f}	54.50^{ij}	48.53^{no}	43.32^{q}	48.78^{g}
AN-PA	64.53^{bc}	57.93^{de}	52.70^{fghij}	58.39^{c}	65.30^{c}	59.18^{ef}	54.15^{jk}	59.55^{c}
AS-SP	61.47^{cd}	55.33^{efgh}	49.03^{jkl}	55.28^{d}	62.12^{d}	56.79^{gh}	50.21^{mn}	56.37^{d}
AS-TS	62.53^{c}	56.20^{ef}	50.20^{ijk}	56.31^{d}	63.53^{cd}	57.20^{fgh}	51.25^{lm}	57.33^{d}
AS-PA	70.33^{a}	64.97^{bc}	58.40^{de}	64.57^{a}	71.29^{a}	65.15^{c}	60.00^{e}	65.48^{a}
Mean	58.77^{a}	52.94^{b}	46.88^{c}		59.34^{a}	53.64^{b}	47.69^{c}	
$F_{water\ regimes\ x\ fertilizers}$ = 0.1705327^{ns}					$F_{water\ regimes\ x\ fertilizers}$ = 0.7736148^{ns}			
Leaves dry weight (g plant^{-1})								
Control	22.91^{nop}	19.33^{p}	11.00^{q}	17.75^{g}	21.21^{r}	18.29^{s}	15.30^{t}	18.26^{j}
UR-SP	37.67^{efg}	31.87^{ijk}	26.37^{mn}	31.97^{e}	38.22^{g}	33.06^{k}	27.30^{o}	32.86^{g}
UR-TS	40.08^{de}	33.61^{hij}	28.03^{klm}	33.91^{e}	40.59^{f}	34.12^{j}	28.29^{no}	34.33^{f}
UR-PA	48.93^{ab}	42.90^{cd}	37.53^{efgh}	43.12^{b}	49.52^{b}	44.01^{e}	38.26^{g}	43.93^{b}
AN-SP	33.90^{ghij}	27.77^{lm}	21.87^{op}	27.85^{f}	34.93^{ij}	29.04^{n}	22.47^{q}	28.81^{i}
AN-TS	35.58^{fghi}	29.69^{klm}	23.83^{no}	29.70^{f}	36.26^{h}	30.40^{m}	24.03^{p}	30.23^{h}
AN-PA	46.23^{bc}	39.63^{de}	34.40^{fghij}	40.09^{c}	47.18^{c}	40.77^{f}	35.33^{hi}	41.09^{c}
AS-SP	43.17^{cd}	37.03^{efgh}	30.73^{jkl}	36.98^{d}	44.14^{e}	38.13^{g}	31.36^{lm}	37.87^{e}
AS-TS	44.23^{c}	37.90^{ef}	31.90^{ijk}	38.01^{d}	45.21^{d}	39.18^{g}	32.17^{kl}	38.85^{d}
AS-PA	52.03^{a}	46.67^{bc}	40.10^{de}	46.27^{a}	53.37^{a}	47.92^{c}	41.17^{f}	47.49^{a}
Means	40.47^{a}	34.64^{b}	28.58^{c}		41.06^{a}	35.49^{b}	29.57^{c}	
$F_{water\ regimes\ x\ fertilizers}$ = 0.1705327^{ns}					$F_{water\ regimes\ x\ fertilizers}$ = 4.7432288*			

Means with the same letter are insignificantly at 5% according to Duncan's test.
N: nitrogen; P: phosphorus; AN: ammonium nitrate; UR: urea; AS: ammonium sulfate; TS: triple superphosphate; SP: single superphosphate; PA: phosphoric acid; FC: field capacity.
*significant at $p \leq 0.001$ and ns = insignificant at $p \geq 0.05$.

Table 2 Different vegetative characteristics of *Swietenia mahagoni* (L.) Jacq. as influenced by N and P forms under different water regimes

Drought / Nutrition	1st season				2nd season			
	100% FC	75% FC	50% FC	Mean	100% FC	75% FC	50% FC	Mean
Stem fresh weight (g plant^{-1})								
Control	68.00 ^{op}	63.32 ^{q}	55.07 ^{r}	62.13 ^{j}	67.14 ^{op}	62.22 ^{q}	53.18 ^{r}	60.84 ^{j}
UR-SP	83.33 ^{ij}	77.65 ^{kl}	71.12 ^{no}	77.37 ^{g}	84.37 ^{i}	79.15 ^{kl}	72.07 ^{n}	78.53 ^{g}
UR-TS	87.33 ^{fgh}	80.95 ^{jk}	73.72 ^{mn}	80.67 ^{f}	86.14 ^{gh}	82.02 ^{j}	73.99 ^{m}	80.72 ^{f}
UR-PA	99.67 ^{b}	93.14 ^{de}	86.84 ^{ghi}	93.21 ^{b}	99.83 ^{b}	94.15 ^{d}	87.40 ^{g}	93.79 ^{b}
AN-SP	76.77 ^{lm}	70.89 ^{no}	64.94 ^{pq}	70.87 ^{i}	78.36 ^{l}	72.09 ^{n}	65.77 ^{p}	72.07 ^{i}
AN-TS	80.50 ^{jk}	74.55 ^{lm}	67.38 ^{p}	74.14 ^{h}	80.63 ^{jk}	74.22 ^{m}	68.47 ^{o}	74.44 ^{h}
AN-PA	95.93 ^{cd}	89.62 ^{efg}	84.72 ^{hi}	90.09 ^{c}	96.51 ^{c}	90.17 ^{f}	85.29 ^{hi}	90.66 ^{c}
AS-SP	90.62 ^{ef}	83.90 ^{hij}	77.82 ^{kl}	84.11 ^{e}	92.20 ^{e}	85.04 ^{hi}	79.20 ^{kl}	85.48 ^{e}
AS-TS	93.19 ^{de}	86.64 ^{ghi}	80.78 ^{jk}	86.87 ^{d}	93.71 ^{d}	87.20 ^{g}	81.57 ^{j}	87.49 ^{d}
AS-PA	103.08 ^{a}	98.26 ^{bc}	89.60 ^{efg}	96.98 ^{a}	104.10 ^{a}	99.21 ^{b}	90.30 ^{f}	97.87 ^{a}
Mean	87.84 ^{a}	81.89 ^{b}	75.20 ^{c}		88.30 ^{a}	82.55 ^{b}	75.72 ^{c}	
$F_{water\ regimes\ x\ fertilizers}$ = 0.2804423^{ns}					$F_{water\ regimes\ x\ fertilizers}$ = 1.8959957*			
Stem dry weight (g plant^{-1})								
Control	49.50 ^{op}	44.82 ^{q}	36.57 ^{r}	43.63 ^{j}	48.18 ^{p}	43.52 ^{q}	34.28 ^{r}	42.00 ^{j}
UR-SP	64.83 ^{ij}	59.15 ^{kl}	52.62 ^{no}	58.87 ^{g}	66.11 ^{h}	61.18 ^{k}	54.20 ^{n}	60.50 ^{g}
UR-TS	68.83 ^{fgh}	62.45 ^{jk}	55.22 ^{mn}	62.17 ^{f}	69.15 ^{g}	62.82 ^{i}	55.78 ^{m}	62.58 ^{f}
UR-PA	81.17 ^{b}	74.64 ^{de}	68.34 ^{ghi}	74.71 ^{b}	82.55 ^{b}	75.55 ^{e}	69.22 ^{g}	75.77 ^{b}
AN-SP	58.27 ^{lm}	52.39 ^{no}	46.44 ^{pq}	52.37 ^{i}	59.43 ^{l}	54.11 ^{n}	48.24 ^{p}	53.93 ^{i}
AN-TS	62.00 ^{jk}	56.05 ^{lm}	48.88 ^{p}	55.64 ^{h}	62.31 ^{ijk}	56.73 ^{m}	49.63 ^{o}	56.22 ^{h}
AN-PA	77.43 ^{cd}	71.12 ^{efg}	66.22 ^{hi}	71.59 ^{c}	78.30 ^{d}	72.50 ^{f}	67.37 ^{h}	72.72 ^{c}
AS-SP	72.12 ^{ef}	65.40 ^{hij}	59.32 ^{kl}	65.61 ^{e}	73.62 ^{f}	66.92 ^{h}	61.40 ^{jk}	67.31 ^{e}
AS-TS	74.69 ^{de}	68.14 ^{ghi}	62.28 ^{jk}	68.37 ^{d}	75.12 ^{e}	68.80 ^{g}	62.61 ^{ij}	68.84 ^{d}
AS-PA	84.58 ^{a}	79.76 ^{bc}	71.10 ^{efg}	78.48 ^{a}	85.29 ^{a}	81.25 ^{c}	72.73 ^{f}	79.76 ^{a}
Total mean	69.34 ^{a}	63.39 ^{b}	56.70 ^{c}		70.00 ^{a}	64.34 ^{b}	57.55 ^{c}	
$F_{water\ regimes\ x\ fertilizers}$ = 0.2804423^{ns}					$F_{water\ regimes\ x\ fertilizers}$ = 2.4395837**			
Shoot fresh weight (g plant^{-1})								
Control	109.21 ^{q}	100.95 ^{r}	84.37 ^{s}	98.18 ^{j}	107.32 ^{r}	98.55 ^{s}	80.86 ^{t}	95.57 ^{j}
UR-SP	139.30 ^{hi}	127.81 ^{lm}	115.79 ^{p}	127.64 ^{g}	140.76 ^{i}	130.62 ^{lm}	117.44 ^{p}	129.61 ^{g}
UR-TS	145.71 ^{g}	132.87 ^{jkl}	120.05 ^{op}	132.88 ^{f}	144.81 ^{g}	134.26 ^{jk}	120.60 ^{no}	133.22 ^{f}
UR-PA	166.90 ^{b}	154.34 ^{e}	142.67 ^{gh}	154.64 ^{b}	168.03 ^{b}	156.20 ^{de}	144.30 ^{gh}	156.18 ^{b}
AN-SP	128.97 ^{lm}	116.95 ^{p}	105.11 ^{qr}	117.01 ^{i}	131.57 ^{klm}	119.53 ^{op}	107.16 ^{r}	119.42 ^{i}
AN-TS	134.38 ^{ijk}	122.54 ^{no}	109.51 ^{q}	122.14 ^{h}	135.13 ^{j}	122.75 ^{n}	111.79 ^{q}	123.22 ^{h}
AN-PA	160.47 ^{cd}	147.56 ^{fg}	137.42 ^{hij}	148.48 ^{c}	161.82 ^{c}	149.35 ^{f}	139.44 ^{i}	150.20 ^{c}
AS-SP	152.09 ^{ef}	139.23 ^{hi}	126.85 ^{mn}	139.39 ^{e}	154.32 ^{e}	141.83 ^{hi}	129.41 ^{m}	141.85 ^{e}
AS-TS	155.72 ^{de}	142.84 ^{gh}	130.98 ^{klm}	143.18 ^{d}	157.24 ^{d}	144.40 ^{gh}	132.81 ^{jkl}	144.82 ^{d}
AS-PA	173.41 ^{a}	163.22 ^{bc}	148.00 ^{fg}	161.54 ^{a}	175.39 ^{a}	164.36 ^{c}	150.29 ^{f}	163.35 ^{a}
Mean	146.62 ^{a}	134.83 ^{b}	122.08 ^{c}		147.64 ^{a}	136.18 ^{b}	123.41 ^{c}	
$F_{water\ regimes\ x\ fertilizers}$ = 0.3523157^{ns}					$F_{water\ regimes\ x\ fertilizers}$ = 1.4705977^{ns}			
Shoot dry weight (g plant^{-1})								
Control	72.41 ^{q}	64.15 ^{r}	47.57 ^{s}	61.38 ^{j}	69.39 ^{s}	61.81 ^{t}	49.58 ^{u}	60.26 ^{j}
UR-SP	102.50 ^{hi}	91.01 ^{lm}	78.99 ^{p}	90.84 ^{g}	104.33 ^{jk}	94.24 ^{mn}	81.50 ^{q}	93.36 ^{g}
UR-TS	108.91 ^{g}	96.07 ^{jkl}	83.25 ^{op}	96.08 ^{f}	109.74 ^{h}	96.93 ^{l}	84.07 ^{p}	96.91 ^{f}
UR-PA	130.10 ^{b}	117.54 ^{e}	105.87 ^{gh}	117.84 ^{b}	132.06 ^{b}	119.56 ^{e}	107.48 ^{i}	119.70 ^{b}
AN-SP	92.17 ^{lm}	80.15 ^{p}	68.31 ^{qr}	80.21 ^{i}	94.36 ^{mn}	83.15 ^{pq}	70.70 ^{s}	82.74 ^{i}
AN-TS	97.58 ^{ijk}	85.74 ^{no}	72.71 ^{q}	85.34 ^{h}	98.56 ^{l}	87.14 ^{o}	73.67 ^{r}	86.46 ^{h}
AN-PA	123.67 ^{cd}	110.76 ^{fg}	100.62 ^{hij}	111.68 ^{c}	125.48 ^{d}	113.27 ^{g}	102.70 ^{k}	113.81 ^{c}
AS-SP	115.29 ^{ef}	102.43 ^{hi}	90.05 ^{mn}	102.59 ^{e}	117.76 ^{f}	105.05 ^{j}	92.76 ^{n}	105.19 ^{e}
AS-TS	118.92 ^{de}	106.04 ^{gh}	94.18 ^{klm}	106.38 ^{d}	120.33 ^{e}	107.98 ^{i}	94.77 ^{m}	107.69 ^{d}
AS-PA	136.61 ^{a}	126.42 ^{bc}	111.20 ^{fg}	124.74 ^{a}	138.65 ^{a}	129.18 ^{c}	113.90 ^{g}	127.24 ^{a}
Mean	109.82 ^{a}	98.03 ^{b}	85.28 ^{c}		111.07 ^{a}	99.83 ^{b}	87.11 ^{c}	
$F_{water\ regimes\ x\ fertilizers}$ = 0.3523157^{ns}					$F_{water\ regimes\ x\ fertilizers}$ = 1.9207733*			

Means with the same letter are insignificantly at 5% according to Duncan's test.
N: nitrogen; P: phosphorus; AN: ammonium nitrate; UR: urea; AS: ammonium sulfate; TS: triple superphosphate; SP: single superphosphate; PA: phosphoric acid; FC: field capacity.
*significant at $p \leq 0.05$, **significant at $p \leq 0.01$ and ns = insignificant at $p \geq 0.05$.

Table 3 Different vegetative characteristics of *Swietenia mahagoni* (L.) Jacq. as influenced by N and P forms under different water regimes

Drought / Nutritious	1st season				2nd season			
	100% FC	75% FC	50% FC	Mean	100% FC	75% FC	50% FC	Mean
Root fresh weight (g plant^{-1})								
Control	33.17^{kl}	31.30^{lm}	29.22^{m}	31.23^{i}	31.48^{p}	29.83^{q}	28.20^{r}	29.84j
UR-SP	39.33^{efgh}	37.47^{ghi}	35.20^{ijk}	37.33^{f}	40.38^{hi}	38.22^{jk}	36.31^{lm}	38.30^{g}
UR-TS	40.27^{efg}	38.23^{fghi}	36.31^{hij}	38.27^{f}	41.57^{gh}	39.33^{ij}	37.26^{kl}	39.39^{f}
UR-PA	48.37^{ab}	45.97^{bc}	44.66^{cd}	46.33^{b}	49.40^{b}	46.30^{cd}	45.41^{de}	47.04^{b}
AN-SP	35.47^{ijk}	33.37^{jkl}	31.10^{lm}	33.31^{h}	37.87^{k}	34.25^{n}	32.47^{op}	34.86 i
AN-TS	37.53^{ghi}	35.24^{ijk}	33.12^{kl}	35.30^{g}	38.40^{jk}	35.83^{m}	33.53^{no}	35.92^{h}
AN-PA	46.77^{bc}	44.34^{cd}	42.15^{de}	44.42^{c}	47.13^{c}	45.43^{de}	43.30^{f}	45.29^{c}
AS-SP	42.43^{de}	40.00^{efg}	38.11^{fghi}	40.18^{e}	43.35^{f}	41.50^{gh}	39.28^{ij}	41.38^{e}
AS-TS	44.50^{cd}	42.14^{de}	41.12^{ef}	42.59^{d}	44.63^{e}	42.37^{fg}	41.63^{gh}	42.88^{d}
AS-PA	49.93^{a}	48.66^{ab}	46.22^{bc}	48.27^{a}	50.85^{a}	49.27^{b}	47.25^{c}	49.12^{a}
Total Mean	41.78^{a}	39.67^{b}	37.72^{c}		42.51^{a}	40.23^{b}	38.46^{c}	
$F_{water\ regimes\ x\ fertilizers}$ = 0.089476^{ns}					$F_{water\ regimes\ x\ fertilizers}$ = 0.8212076^{ns}			
Root dry weight (g plant^{-1})								
Control	16.97^{hij}	15.10^{ijk}	13.02^{k}	15.03^{g}	15.43^{pq}	14.44^{q}	12.59^{r}	14.16^{i}
UR-SP	21.13^{defg}	19.27^{fgh}	17.00^{hij}	19.13^{e}	22.33^{gh}	20.30^{ijk}	18.65^{lmn}	20.43^{f}
UR-TS	22.07^{drf}	20.03^{efgh}	18.11^{ghi}	20.07^{e}	23.22^{fg}	21.53^{hi}	19.43^{klm}	21.39^{e}
UR-PA	30.17^{a}	27.77^{ab}	26.46^{bc}	28.13^{a}	31.45^{a}	29.16^{b}	27.13^{c}	29.25^{a}
AN-SP	17.27^{hi}	15.17^{ijk}	13.90^{jk}	15.44^{g}	18.27^{mn}	16.50^{op}	14.22^{q}	16.33^{h}
AN-TS	19.33^{fgh}	17.04^{hij}	14.92^{ijk}	17.10^{f}	19.79^{jkl}	17.86^{no}	15.36^{pq}	17.67^{g}
AN-PA	28.57^{ab}	26.14^{bc}	23.95^{cd}	26.22^{b}	29.21^{b}	27.21^{c}	24.84^{e}	27.09^{b}
AS-SP	24.23^{cd}	21.80^{def}	19.91^{efgh}	21.98^{d}	25.43^{de}	23.00^{fg}	21.20^{hij}	23.21^{d}
AS-TS	26.30^{bc}	23.94^{cd}	22.92^{de}	24.39^{c}	26.67^{cd}	24.34^{ef}	23.17^{fg}	24.73^{c}
AS-PA	29.73^{a}	28.46^{ab}	26.02^{bc}	28.07^{a}	31.23^{a}	29.28^{b}	27.70^{c}	29.41^{a}
Mean	23.58^{a}	21.47^{b}	19.62^{c}		24.30^{a}	22.36^{b}	20.43^{c}	
$F_{water\ regimes\ x\ fertilizers}$ = 0.098275^{ns}					$F_{water\ regimes\ x\ fertilizers}$ = 0.4143456^{ns}			
Root length (cm)								
Control	25.73^{q}	27.20^{pq}	30.25^{op}	27.73^{h}	24.50^{q}	26.60^{p}	29.63^{o}	26.91^{j}
UR-SP	32.37^{no}	34.43^{lmn}	37.62^{ijkl}	34.81^{e}	33.25^{m}	35.33^{k}	38.69^{i}	35.76^{g}
UR-TS	34.11^{mn}	36.53^{jklm}	38.99^{ghij}	36.54^{e}	34.70^{kl}	36.77^{j}	39.43^{hi}	37.00^{f}
UR-PA	42.33^{defg}	44.63^{bcde}	46.92^{ab}	44.63^{a}	43.28^{e}	45.70^{d}	48.80^{b}	45.93^{b}
AN-SP	28.30^{pq}	30.10^{op}	32.98^{no}	30.46^{g}	29.60^{o}	31.07^{n}	33.93^{lm}	31.54^{i}
AN-TS	30.53^{op}	32.17^{no}	35.39^{klmn}	32.70^{f}	30.93^{n}	32.93^{m}	35.33^{k}	33.07^{h}
AN-PA	40.66^{fghi}	42.16^{defg}	45.14^{bcd}	42.65^{b}	41.47^{fg}	43.24^{e}	46.03^{cd}	43.58^{c}
AS-SP	36.43^{jklm}	38.25^{hijk}	41.19^{efgh}	38.63^{d}	37.33^{j}	39.42^{hi}	42.41^{ef}	39.72^{e}
AS-TS	38.23^{hijk}	40.34^{fghi}	43.23^{cdef}	40.6^{c}	38.77^{i}	40.67^{gh}	43.67^{e}	41.03^{d}
AS-PA	41.77^{defg}	46.01^{abc}	49.12^{a}	45.63^{a}	42.35^{ef}	47.23^{c}	50.94^{a}	46.84^{a}
Mean	35.05^{c}	37.18^{b}	40.08^{a}		35.62^{c}	37.90^{b}	40.89^{a}	
$F_{interaction\ water\ regimes\ -\ fertilizers}$ = 0.1722421*					$F_{interaction\ water\ regimes\ -\ fertilizers}$ = 2.0588859*			
Water use efficiency (WUE)								
Control	2.37^{t}	2.94^{r}	3.79^{l}	3.03^{j}	2.31^{y}	2.85^{x}	3.64^{q}	2.93^{j}
UR-SP	2.98^{qr}	3.67^{lm}	5.03^{g}	3.90^{g}	3.02^{w}	3.75^{p}	5.12^{g}	3.97^{g}
UR-TS	3.10^{q}	3.80^{l}	5.21^{f}	4.04^{f}	3.11^{v}	3.86^{o}	5.26^{f}	4.07^{f}
UR-PA	3.59^{mn}	4.45^{i}	6.25^{b}	4.76^{b}	3.63^{q}	4.50^{k}	6.32^{b}	4.82^{b}
AN-SP	2.74^{s}	3.34^{op}	4.54^{i}	3.54^{i}	2.82^{x}	3.42st	4.65^{j}	3.63^{i}
AN-TS	2.86^{rs}	3.50^{n}	4.75^{h}	3.71^{h}	2.89^{x}	3.52^{r}	4.85^{h}	3.75^{h}
AN-PA	3.45^{no}	4.26^{j}	5.99^{c}	4.57^{c}	3.48^{rs}	4.33^{l}	6.09^{c}	4.64^{c}
AS-SP	3.24^{p}	3.98^{k}	5.50^{e}	4.24^{e}	3.30^{u}	4.07^{n}	5.62^{e}	4.33^{e}
AS-TS	3.34^{op}	4.11^{k}	5.73^{d}	4.39^{d}	3.37^{t}	4.15^{m}	5.82^{d}	4.45^{d}
AS-PA	3.72^{lm}	4.71^{h}	6.47^{a}	4.97^{a}	3.77^{p}	4.75^{i}	6.58^{a}	5.03^{a}
Mean	3.14^{c}	3.88^{b}	5.33^{a}		3.17^{c}	3.92^{b}	5.40^{a}	
$F_{water\ regimes\ x\ fertilizers}$ = 21.272087*					$F_{water\ regimes\ x\ fertilizers}$ = 75.801383*			

Means with the same letter are insignificantly at 5% according to Duncan's test.

N: nitrogen; P: phosphorus; AN: ammonium nitrate; UR: urea; AS: ammonium sulfate; TS: triple superphosphate; SP: single superphosphate; PA: phosphoric acid; FC: field capacity.

*significant at $p \leq 0.001$ and ns = insignificant at $p \geq 0.05$.

Table 4 Nitrogen and phosphorous content of leaves of *Swietenia mahagoni* (L.) Jacq. as influenced by N and P fertilizers forms under different water regimes

Drought / Nutritious	1st season				2nd season			
	100% FC	75% FC	50% FC	Mean	100% FC	75% FC	50% FC	Mean
Nitrogen (%)								
Control	2.98^{r}	2.89^{s}	2.78^{t}	2.88^{j}	2.11^{r}	2.02^{s}	1.91^{t}	2.01^{j}
UR-SP	3.69^{i}	3.63^{j}	3.38^{n}	3.57^{g}	2.82^{i}	2.76^{j}	2.51^{n}	2.70^{g}
UR-TS	3.75^{h}	3.70^{i}	3.46^{m}	3.64^{f}	2.88^{h}	2.83^{i}	2.59^{m}	2.77^{f}
UR-PA	4.03^{b}	3.94^{d}	3.71^{i}	3.89^{b}	3.16^{b}	3.07^{d}	2.84^{i}	3.02^{b}
AN-SP	3.11^{p}	3.06^{q}	2.99^{r}	3.05^{i}	2.24^{p}	2.19^{q}	2.12^{r}	2.18^{i}
AN-TS	3.62^{j}	3.55^{k}	3.30^{o}	3.49^{h}	2.75^{j}	2.68^{k}	2.43^{o}	2.62^{h}
AN-PA	3.96^{d}	3.90^{e}	3.61^{j}	3.82^{c}	3.09^{d}	3.03^{e}	2.74^{j}	2.95^{c}
AS-SP	3.83^{f}	3.77^{h}	3.50^{l}	3.70^{e}	2.96^{f}	2.90^{h}	2.63^{l}	2.83^{e}
AS-TS	3.91^{e}	3.81^{fg}	3.55^{k}	3.76^{d}	3.04^{e}	2.94^{fg}	2.68^{k}	2.89^{d}
AS-PA	4.11^{a}	3.99^{c}	3.80^{g}	3.97^{a}	3.24^{a}	3.12^{c}	2.93^{g}	3.10^{a}
Total mean	3.70^{a}	3.62^{b}	3.41^{c}		2.83^{a}	2.75^{b}	2.54^{c}	
$F_{\text{interaction water regimes - fertilizers}} = 25.60101^{*}$					$F_{\text{interaction water regimes - fertilizers}} = 25.60101^{*}$			
Phosphorus (%)								
Control	0.20^{o}	0.18^{p}	0.16^{q}	0.18^{j}	0.16^{o}	0.14^{p}	0.12^{q}	0.14^{j}
UR-SP	0.29^{i}	0.27^{jk}	0.25^{lm}	0.27^{g}	0.25^{i}	0.23^{jk}	0.21^{lm}	0.23^{g}
UR-TS	0.32^{gh}	0.31^{h}	0.27^{jk}	0.30^{f}	0.28^{gh}	0.27^{h}	0.23^{jk}	0.26^{f}
UR-PA	0.38^{ab}	0.36^{cd}	0.32^{gh}	0.35^{b}	0.34^{ab}	0.32^{cd}	0.28^{gh}	0.31^{b}
AN-SP	0.27^{jk}	0.25^{lm}	0.23^{n}	0.25^{i}	0.23^{jk}	0.21^{lm}	0.19^{n}	0.21^{i}
AN-TS	0.28^{ij}	0.26^{kl}	0.24^{mn}	0.26^{h}	0.24^{ij}	0.22^{kl}	0.20^{mn}	0.22^{h}
AN-PA	0.37^{bc}	0.35^{de}	0.31^{h}	0.34^{c}	0.33^{bc}	0.31^{de}	0.27^{h}	0.30^{c}
AS-SP	0.34^{ef}	0.32^{gh}	0.28^{ij}	0.31^{e}	0.30^{ef}	0.28^{gh}	0.24^{ij}	0.27^{e}
AS-TS	0.35^{de}	0.33^{fg}	0.29^{i}	0.32^{d}	0.31^{de}	0.29^{fg}	0.25^{i}	0.28^{d}
AS-PA	0.39^{a}	0.37^{bc}	0.35^{de}	0.37^{a}	0.35^{a}	0.33^{bc}	0.31^{de}	0.33^{a}
Mean	0.32^{a}	0.30^{b}	0.27^{c}		0.28^{a}	0.26^{b}	0.23^{c}	
$F_{\text{interaction water regimes - fertilizers}} = 1.1^{ns}$					$F_{\text{interaction water regimes - fertilizers}} = 1.1^{ns}$			

Means with the same letter are insignificant at 5% according to Duncan's test.
AN: ammonium nitrate; UR: urea; AS: ammonium sulfate; TS: triple superphosphate; SP: single superphosphate; PA: phosphoric acid; FC: field capacity.
*significant at $p \leq 0.001$ and ns = insignificant at $p \geq 0.05$.

Discussion

Influencing of water regime

Water deficit is the main common environmental factor that determines crop productivity. Global climate change increases the vacillation of severe drought conditions, adversely affecting the morphology, physiology, and biochemistry of plants (Basu et al. 2016). The threat of drought causes morphological and physiological changes in higher plants Ghorbani et al. (2019). Water is an important factor in the growth and improvement of the plant; however, an increasing or decreasing amount of water supply negatively impacts its overproduction and survival of the plants (Kang et al. 2024). Drought stress has been recognized as a limiting element in this study, influencing numerous aspects of vegetative and biochemical characteristics of plant growth. In the present study, all vegetative growth (leaves number, stem height, fresh and dry weights of root, stem shoot, and leaves), and biochemical characteristics (N and P content of leaves) of mahogany were negatively influenced by different degrees of drought stress, except for root length and plant WUE were increased with increasing drought conditions. The decline in growth characteristics in response to reduced irrigation levels appears to be connected to a decrease in cell turgor, and the derogation seen in plants irrigated with 75% or 50% FC must be attributed to lower turgor pressure induced by low soil water availability, which involves processes such as cell division and elongation (Riboldi et al. 2016). These results of seedling growth traits of mahogany seedlings were in harmony with the findings of Gullape et al. (2022) on soybean seedlings (*Glycine max* L.), and Wang et al. (2023), on Mongolian oak (*Quercus mongolica* Fisch. ex Ledeb.) tree.

Concerning the decline in stem height, Lisar et al. (2012) reported that a plant's height constitutes one of the essential criteria usually used to estimate the extent of drought stress. Drought induces the plant stem to expand slowly, the plant stays dwarfed, and its leaf growth diminishes (Ahmad et al. 2019). A plant's height impacted by water stress could be due to a hormonal imbalance between abscisic acid and cytokinin hormones, which affects plant growth by altering cell wall elongation (Ahmad et al. 2019). Furthermore, Abdallah et al. (2019) stated that the derogating in growth features could be related to a detraction

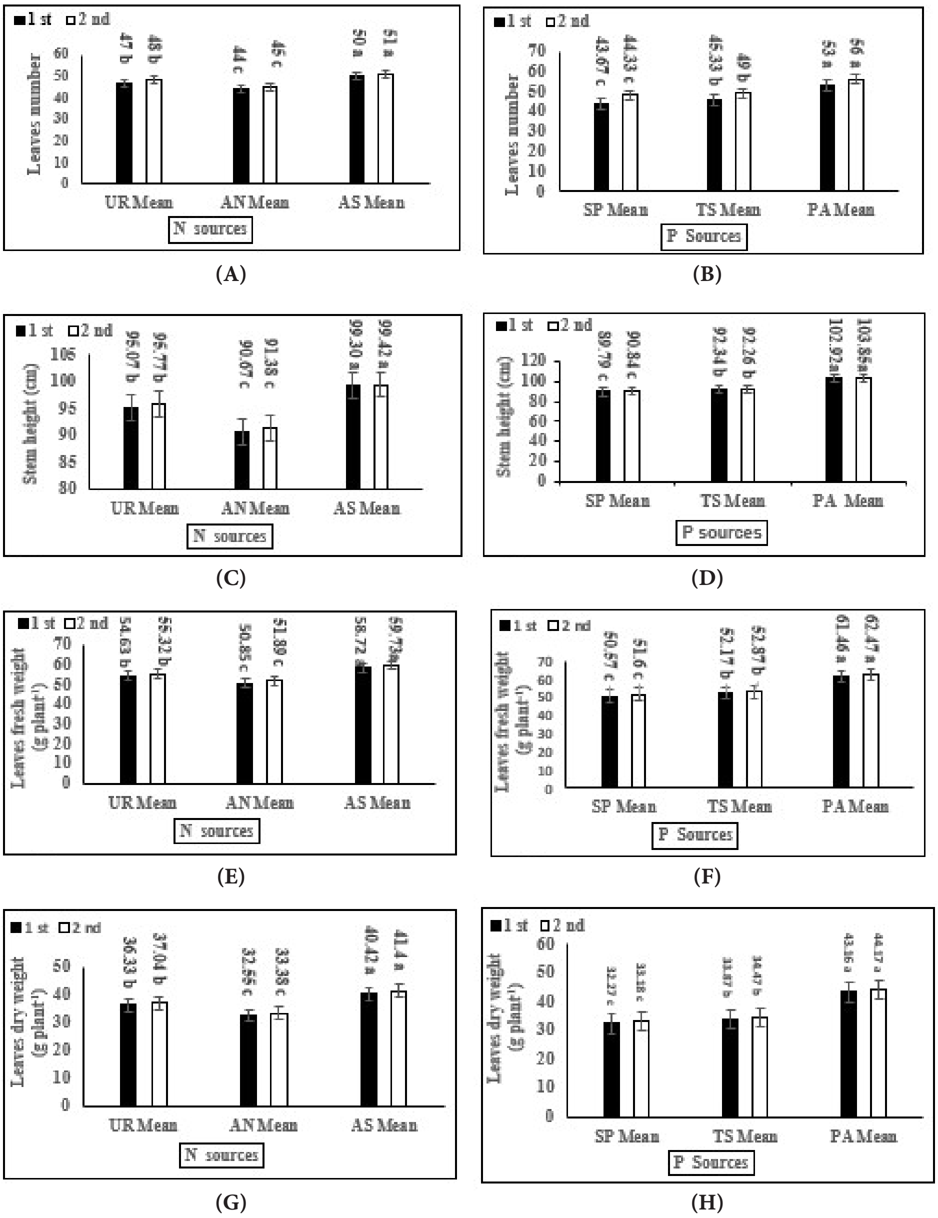

Fig. 1 The effect of the mean fertilization with N and P sources on the leaves number (A, B), stem height (C, D), and leaves fresh (E, F) and dry (G, H) weights (g plant^{-1}). Means followed by the same letter are not significant at 5% according to Duncan's test. Vertical bars indicate standard error. N: nitrogen; P: phosphorus; AN: ammonium nitrate; UR: urea; AS: ammonium sulfate; TS: triple superphosphate; SP: single superphosphate; PA: phosphoric acid.

in the activity of meristematic tissues, which contribute to elongation during drought stress.

Concerning the decline in fresh and dry weights of stems, leaves, and roots of the plant with decreasing soil water. Meng et al. (2023) indicated that there was declining in *Pinus sylvestris* var. *mongolica* plant fresh and dry weights with increasing soil drought, and that drought stress had a negative influence on the weights of the fresh and dry matter of leaves. Zhao et al. (2020) explained that under both moderate (75% FC) and severe (50% FC) drought stress, weights of the fresh and dry substances of the shoot and aerial biomass were reduced significantly because the lowering in photosynthesis caused by the water deficit affected the development of the leaves, which were unable to expand completely. The amount of photosynthetic effective radiation intercepted by the plant dropped, which resulted in a reduction in its height and matter buildup, leading to a reduction in the production of the plant.

Regarding the enhancement of root length and WUE with increasing degrees of drought stress. This finding follows El-Sayed et al. (2022), who reported that after applying three irrigation intervals (5, 7, and 9 days) on the seedlings of mahogany, they found that stressed seedlings had the longest roots. Wasaya et al. (2018) indicated that field soil moisture contents increased with soil depth; hence, an extended root system could reach a greater soil volume to collect available water and because roots are the sole organ that receives water from the soil, they are the primary organs that respond to perceive and keep up plant growth under drought stress. Drought-tolerant plants achieve greater WUE by minimizing water loss. This can occur through the closure of their stomata when water is scarce, as indicated by Farooq et al. (2009).

Regarding the decline in N and P leaves content with de-

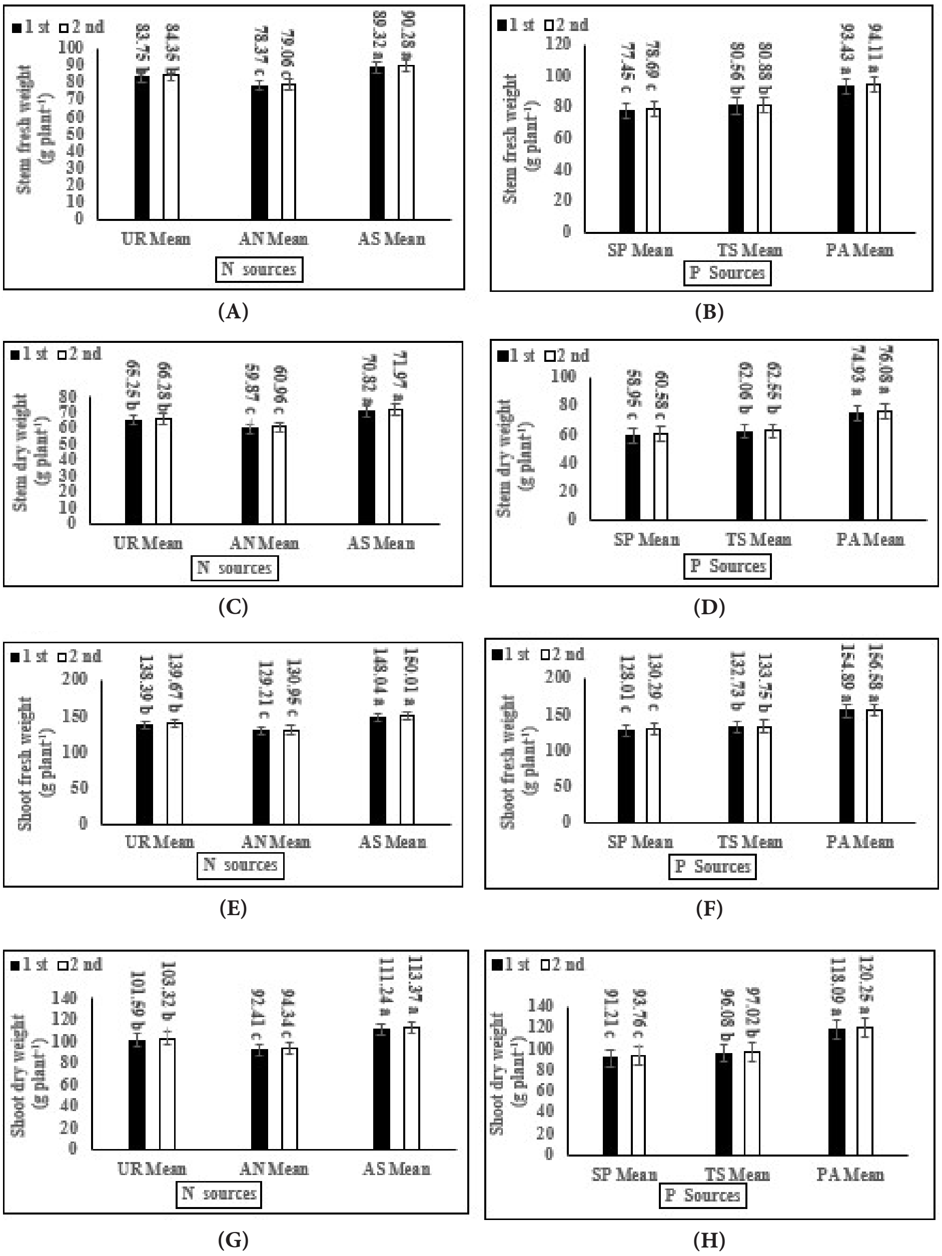

Fig. 2 The effect of the mean fertilization with N and P sources on the stem fresh (A, B) and dry (C, D) weights, shoot fresh (E, F), and dry (G, H) weight (g plant^{-1}). Means followed by the same letter are not significant at 5% according to Duncan's test. Vertical bars indicate standard error. N: nitrogen; P: phosphorus; AN: ammonium nitrate; UR: urea; AS: ammonium sulfate; TS: triple superphosphate; SP: single superphosphate; PA: phosphoric acid.

creasing soil water content; it became apparent that the highest values of N and P were obtained in the case of 100% FC, this conclusion is consistent with the study of Abdel-Magied et al. (2022) on *Eucalyptus citriodora* Hook seedlings, that irrigation intervals at 7 days reduced the values of N and P elements in leaves more than 2 and 5 days. Reduction in N and P content in leaves minimizes the absorption of important nutrients during drought conditions (Nohong and Nompo 2015). Soil water scarcity inhibits micro-organisms' mineralization for organic matter, which ultimately decreases N and P availability, uptake, and transportation, affecting the utilization of nutrients by plant roots (Wasaya et al. 2018). Moreover, drought impacts the mobility of nutrients and limits the transfer of nutrients between roots and aerial organs, thereby reducing the uptake of N and P (Suriyagoda et al. 2014).

Influence of N and P nutrition

Based on a study by Yin et al. (2009), both nutrients and water are two of the important factors determining tree growth, and they interact. Many studies indicate that when trees are not water-stressed, fertilization is beneficial, and irrigation can be successful when nutrients are readily available. Khan et al. (2014) indicated that nutrient combinations perform better than individual nutrients. Interactions between nutrients occur in plants when the supply of one nutrient influences the absorption, distribution, or function of another nutrient, resulting in altered plant growth responses. Interactions can be advantageous (synergistic) or destructive (antagonistic).

In the present study, results revealed that all applications with different nutrition of N and P fertilizer (UR-SP, UR-TS, UR-PA, AN-SP, AN-TS, AN-PA, AS-SP, AS-TS, and

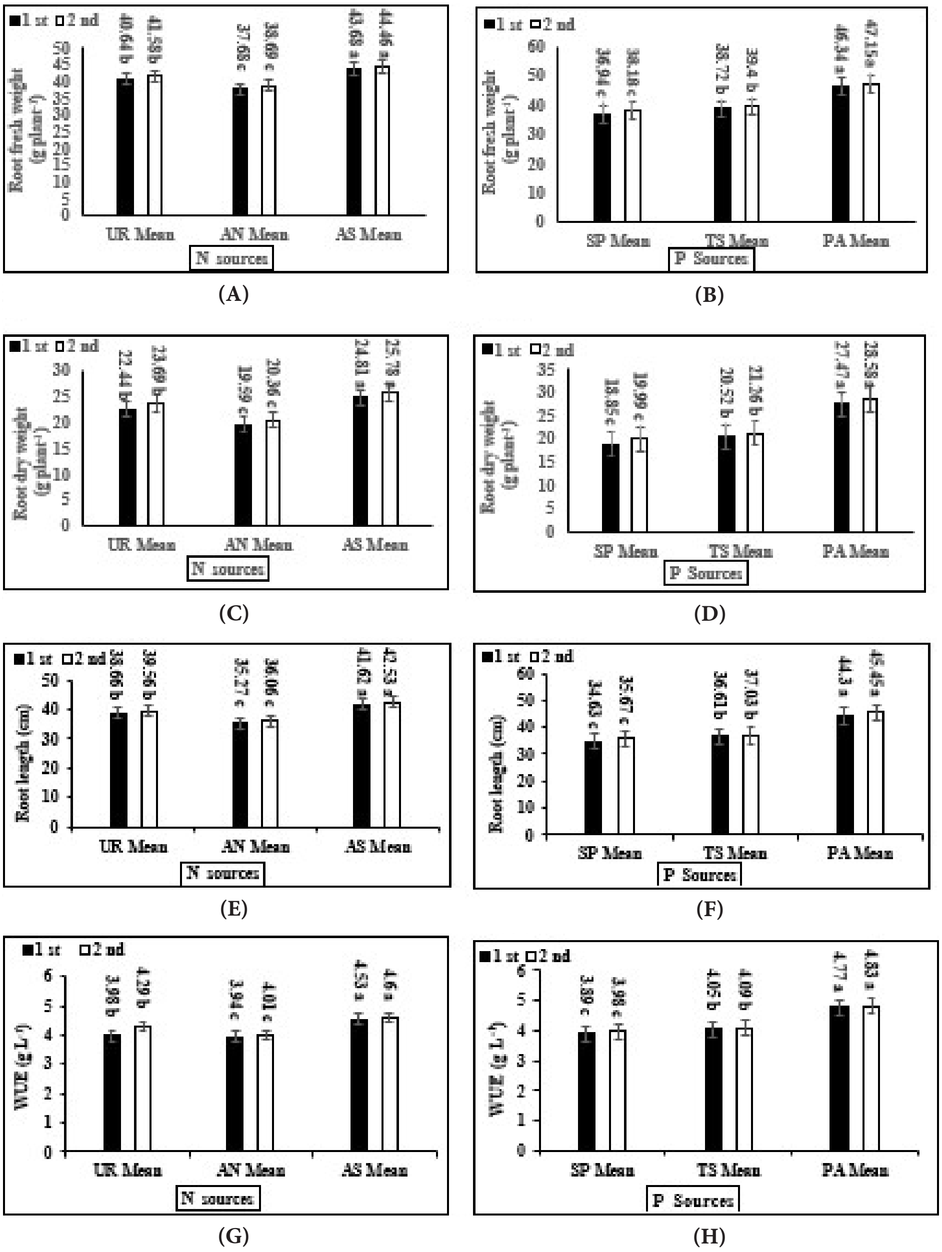

Fig. 3 The effect of the mean fertilization with N and P sources on the root fresh (A, B) and dry (C, D) weights (g plant^{-1}), root length (E, F), and water use efficiency WUE (G, H). Means followed by the same letter are not significant at 5% according to Duncan's test. Vertical bars indicate standard error. N: nitrogen; P: phosphorus; WUE: water use efficiency; AN: ammonium nitrate; UR: urea; AS: ammonium sulfate; TS: triple superphosphate; SP: single superphosphate; PA: phosphoric acid.

AS-PA), strictly enhance all growth characteristics (root length, stem height, number of leaves, the fresh and dry weights of shoots, roots, stems, and leaves, WUE and N and P contents of leaves). Our result indicated that a combination of AS-PA had the highest significant effect on all studied growth characteristics; these results were in harmony with the findings of Abd-Elrahman et al. (2022), on Eggplants (*Solanum melongena* L.).

Regarding other N and P combinations, Abo-Alhassan et al. (2022) indicated that treatment of *Vicia faba* L. plants with a combination of UR-SP under two irrigation regimes (well [80% FC] and severe [40% FC]), significantly enhances the dry weights of shoot, root and total plant. Li et al. (2022) revealed that using a combination of UR-TS on maize (*Zea mays* L.) under two deficit irrigation levels enhances plant growth. Kizilgeci (2019) indicated that the application of a combination of AN-TS on wheat (*Triticum aestivum* L.) plants under dryland conditions, significantly enhances the stem height of the plant. Ibrahim and El-Kassas (2016) indicated that fertilization with AS-SP increased the growth (stem height, leaves number, total dry biomass) of *Vigna unguiculata* L. plants under three water field capacities (50%, 75%, and 100% FC). Farrag et al. (2016) used a combination of AS-TS on potato (*Solanum tuberosum* L.) cultivars under different irrigation levels (50, 75, and 100% FC), they found that fertilizer improved the plant growth (leaves number, and fresh and dry weights of the plant). Guan et al. (2016) confirmed that usage of a combination of AN-SP significantly enhances the growth of wheat (*Triticum aestivum* L.) under two distinct irrigated conditions (75 and 50% FC).

Regarding the result of mean fertilization with N forms

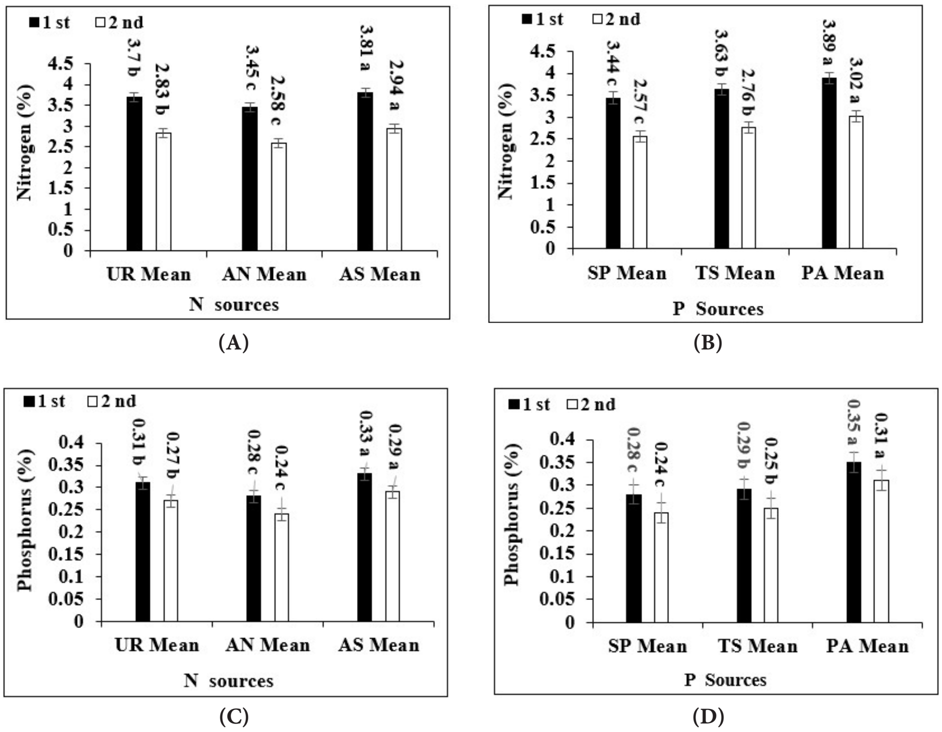

Fig. 4 The effect of the mean fertilization with N and P sources on the nitrogen (A, B) and phosphorous (C, D) contents of leaves. Means followed by the same letter are not significant at 5% according to Duncan's test. Vertical bars indicate standard error. AN: ammonium nitrate; UR: urea; AS: ammonium sulfate; TS: triple superphosphate; SP: single superphosphate; PA: phosphoric acid.

(UR, AS, and AN) and P forms (TS, PA, and SP), AS and PA fertilizers had significantly the highest value of all studied characteristics, while the lowest was obtained from AN and SP fertilizers. Cardoso et al. (2015), the combination of ammonium and phosphate in Mahogany creates a considerable advantageous effect of ammonium supply for Mahogany cultivation. Hence, ammonium availability improves the utilization of phosphate fertilizer, supporting the growth of Mahogany in the field. In contrast, the observed antagonism between nitrate and phosphate uptake represents a significant disadvantage of nitrate supply for Mahogany cultivation. As a result, by comparing the effect of the mean fertilization with N forms, the AS source significantly had the highest value, while the smallest was obtained from the AN source.

Ezzat et al. (2011) indicated that the better effect of AS can be linked to the acidic component's involvement in lowering soil pH and facilitating nutrient absorption by plant roots, resulting in a large increase in elemental uptake and faster plant growth. Fageria et al. (2010), indicated that AS caused a higher reduction in soil pH than UR. AS fertilization contributed to around 40% of soil pH variation, while UR fertilization contributed only 26% of soil pH variation. Nasim et al. (2012) explain that AS contains Sulphur to meet the nutritional requirements of growing plants and decrease the pH of the soil. Also, AS sources include Sulphur, which is a component of succinyl Co-A and a component of chlorophyll in leaves; these components accelerated photosynthesis, which eventually forced vegetative growth (Rasool et al. 2013).

Concerning other N forms; Chien et al. (2011), stated that AS may provide some agronomic and ecological benefits over UR and AN because it lacks toxicity to plants, doesn't lose NH_3 via volatilizing, increasing soil P and micronutrient availability, and lowers denitrification, which could improve N efficiency. Because AN is not absorbed by the soil complex, important amounts of AN can be leached (Wang et al. 2015). Sabir et al. (2013) recorded that UR could increase plant growth by increasing macro- and micronutrient uptake in shoots and roots.

Concerning PA source, Hussain et al. (2011) indicated that PA contains a considerably greater amount of P available form than other solid fertilizers, so when roots absorb this available P, enhancing uptake of macro and micronutrients, increasing significantly plant height and shoot biomass. Mohamed (2021) revealed that PA lowers soil pH, which may enhance the availability of minerals by making them more soluble and available for absorption by plants, hence increasing the production of vegetative growth. As noted by Holloway et al. (2001), PA might be less reactive to soil components due to the dilute solution that contains the P ion in the soil around the fluid stream than around the granule (SP and TS) forms. Lower absorption of P to plant roots from granular P fertilizers in arid and semi-arid soils owing to the presence of free lime, Ca, and Mg (Hopkins and Ellsworth 2005). As a result, by comparing the mean fertilization with P forms, the PA source significantly had the maximum value, while the minimum was obtained from SP.

Concerning enhancing root length and WUE by using N and P fertilizers, Al-Taher et al. (2005) indicated that enhancing root length probably may be due to the effect of the N element on the biological processes that take place in the plant. It's a necessary element in the building of the amino acid tryptophan, which is used in the formation of auxin and later plays an important role in the elongation of plants and increases the activation of meristem cells, increasing cell division. Moreover, the growth of roots will be increased, which causes an increase in the WUE and minerals and then increases vegetative growth. P application could improve plant tolerance to water stress by enhancing the root system and increasing plant accessibility to a wide range of water and nutrient sources (Razaq et al. 2017). Finally, N and P could minimize the effects of drought stress and increase plant growth by monitoring photoassimilates through increasing membrane integrity and decorating photooxidation, as proposed by Akram et al. (2014). Furthermore, N and P appear to be involved in mitigating drought stress by improving dry matter production, higher WUE, and an increase in membrane integrity (Wu et al. 2018).

Conclusions

From our study, it was found that applying different forms of N and P sources alleviated drought stress by increasing plant growth (root length, stem height, fresh and dry weights of the shoot, root, stem, and leaves, WUE, and N and P content of leaves). A combination of AS-PA, AS, and PA had the best results under drought conditions while AN and TS had the lowest effect. The authors recommended that under drought conditions it is very useful to fertilize the crops and trees with a combination of AS-PA. Also, more physiological and genetic investigations are required on the Mahogany tree in Egypt, to increase its wood production, which means money and to fill a gap in the Egyptian wood market.

Supplementary Information

Supplementary information accompanies this paper at https://doi.org/10.5141/jee.24.113.

Table S1. Means of the temperature (night and day) for the whole year during the first and second growing seasons of *Swietenia mahagoni* (L.) Jacq. **Table S2.** Principal characteristics of physical and chemical analysis of the agricultural soil in both growing seasons of *Swietenia mahagoni* (L.) Jacq. **Table S3.** Experimental design of application of N and P fertilizers during the cultivation of *Swietenia mahagoni* (L.) Jacq. in the field. **Table S4.** Chemical analysis of the tap water for irrigation during cultivation of *Swietenia mahagoni* (L.) Jacq.

Abbreviations

AN: Ammonium nitrate
ANOVA: Analysis of variance
AS: Ammonium sulfate
FC: Field capacity
N: Nitrogen
P: Phosphorus
PA: Phosphoric acid
SP: Superphosphate
TS: Triple superphosphate
UR: Urea
WUE: Water use efficiency

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Authors' contributions

DAA, MM conception and design, acquisition, analysis, statistical analysis, and interpretation of results. Also, drafting the article and revising it. They approved the final version to be submitted for publication. AA, AS, ME drafted the article and revising it. They approved the final version to be submitted for publication.

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Availability of data and materials

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Ethics approval and consent to participate

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Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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