ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND `APPLIED SCIENCES

Ph.D THESIS

Abdalla Eisa Tagaldeen ADAM

INVESTIGATING THE DEVELOPMENTAL BIOLOGY AND MANAGEMENT POSSIBILITIES FOR TWO MESQUITE SPECIES [*Prosopis farcta* (Banks & Sol.) F.J. Mac. and *Prosopis juliflora* (Sw.) DC.]

DEPARTMENT OF PLANT PROTECTION

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We certify that this thesis has been reviewed and approved for the degree of **Doctor of Philosophy** of science by the following dissertation committee board on ……/…..../2019.

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ABSTRACT

Ph.D THESIS

INVESTIGATING THE DEVELOPMENTAL BIOLOGY AND MANAGEMENT POSSIBILITIES FOR TWO MESQUITE SPECIES [*Prosopis farcta* (Banks & Sol.) J.F. Mac. and *Prosopis juliflora* (Sw.) DC.]

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Dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.] is an invasive weed most commonly infest non-irrigated areas along the Eastern Mediterranean region of Turkey. Whereas common mesquite [*Prosopis juliflora* (Sw.) DC.] was introduced to Sudan in early 1900's and currently become an invasive weed causing a major threat to cropland and natural ecosystems. In the present research, temperature requirements for seed germination of the two mesquite species were determined. As a result, optimum temperatures were found to be 35°C and 30°C for *P. juliflora* and *P. farcta*, respectively. Moreover, the effect of some mechanical and physical treatments such as pre-chilling, preheating, and seed cutting on the germinatability of these two mesquite species was studied. In addition, the phenological growth stages of dwarf mesquite have been determined when the vegetative growth, development and reproductive phenology of this plant were precisely studied. As an attempt to combine the results obtained from the weed biology and management studies, the efficacy of different herbicides on *P. farcta* and *P. juliflora* was investigated by conducting several greenhouse and field experiments. . According to the results obtained from the greenhouse experiments, all tested herbicides provided effective control for the two species. However, under the field conditions, only application of 2,4-D+picloram has demonstrated an acceptable effect on dwarf mesquite. Furthermore, as an alternative management option, impact of indigenous seed-feeding insects on dwarf mesquite was investigated. In biological control studies, five insect species of Bruchid family were identified and they were considered potential biological control agents for management of dwarf mesquite.

Keywords: Mesquite management, *Prosopis farcta*, *Prosopis juliflora*

ÖZ

DOKTORA TEZİ

İKI ÇETİ TÜRÜNÜN [*PROSOPIS FARCTA* (BANKS & SOL.) F.J. MAC. VE *PROSOPIS JULIFLORA* (SW.) DC.]'NIN GELIŞME BIYOLOJISI VE MÜCADELE OLANAKLARININ ARAŞTIRILMASI

Abdalla Eisa Tagaldeen ADAM

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Çeti [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], istilacı bir yabancı ot türü olup, genel olarak Türkiye'nin Doğu Akdeniz Bölgesindeki sulanmayan alanlarında sorun olmaktadır. Sudan Çetisi [*Prosopis juliflora* (Sw.) DC.] ise, Sudan'a 1990'lerin başında taşınmış olup, şu an ekim alanlarına ve doğal ekosistemlere büyük bir tehdit oluşturan istilacı yabancı ot türü haline gelmiştir. Bu araştırmada, iki Çeti türünün tohum çimlenmesi için sıcaklık gereksinimleri belirlenmiştir. Sonuç olarak, *P. farcta* ve *P. juliflora* için optimum çimlenme sıcaklıklarının sırasıyla 30°C ve 35°C olduğu saptanmıştır. Ayrıca, ön üşütme, ön ısıtma ve tohum kesme gibi bazı mekanik ve fiziksel işlemlerin bu iki yabancı ot türünün tohumlarının çimlenmesine olan etkisi incelenmiştir. Aynı zamanda, *P. farcta*'nın vejetatif büyümesi, gelişmesi ve çoğalması gibi fenolojik büyüme aşamalarını tarla koşullarında çalışılarak tespit edilmiştir. Yabancı ot biyolojisi ve mücadelesinden alınan sonuçları birleştirmek amacıyla birkaç sera ve tarla denemesi yürütülerek farklı herbisitlerin *P. farcta* ve *P. juliflora* üzerindeki etkinliği incelenmiştir. Sera denemelerin sonuçlarına göre, test edilen tüm herbisitlerin iki Çeti türü için etkili kontrol sağlamıştır. Tarla koşullarında ise, Çeti üzerinde sadece 2,4-D+picloram uygulaması kabul edilebilir bir etki göstermiştir. Çetinin biyolojik mücadelesine yönelik olarak, Çeti tohumu üzerinde beslenen böceklerin Çeti üzerindeki etkisi araştırılmıştır. Biyolojik mücadele çalışmalarında, Bruchid familyasına ait beş tür tanımlanıp, Çeti mücadelesi için potansiyel Biyolojik mücadele etmenleri olarak kabul edilmiştir.

Anahtar Kelimeler: *Prosopis farcta*, *Prosopis juliflora*, istilacı yabancı otlar

EXTENDED ABSTRACT

Mesquite is a leguminous tree or shrub in the genus *Prosopis*, which contains about 47 known species. Approximately 40 *Prosopis* species are native to the Americas (Burkart, 1976; Pasiecznik, et al. 2001). However, as a result of the increased international transportation and human mobility many mesquite species have been purposefully or accidentally introduced to new environments (van Klinken and Campbell, 2001; Mauremootoo, 2006; Ogutu and Mauremootoo, 2006). Eventually, mesquite has become an invasive plant spreading mainly in the arid and semiarid regions worldwide (Pasiecznik, et al. 2004; van Klinken et al. 2006). In this study, the biology and management of the common mesquite (*P. juliflora*), an invasive weed in Sudan, and dwarf mesquite (*P. farcta*), a problematic invasive weed in Turkey, have been investigated to provide a scientific basis for developing an effective control for these weeds.

Therefore, this research was aimed (i) to investigate the temperature requirements for seed germination of the two mesquite species, (ii) to determine the impact of some mechanical and physical treatments on the seed dormancy of the two mesquite plants (iii) to determine the efficacy of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine, and 2,4-D triisopropylamine plus picloram) on the two mesquite species under greenhouse and field conditions; (iv) to identify the indigenous herbivore insects feeding on dwarf mesquite and their potential as biological control agents against dwarf mesquite, and (v) to study the phenological growth stages of dwarf mesquite.

The germination experiments were performed in the laboratory conditions where the seeds of common and dwarf mesquite were placed in Petri dishes and tested for germination under a constant temperature range from 5°C to 45°C, with 5°C intervals. Afterward, the germination percentages were determined at the end of the experiment, which lasted for a 28-day period. To compare different methods

for breaking the physical seed dormancy of mesquite, seeds were subjected to pre-chilling at -5°C and +5°C, pre-heating at 40°C for 24 hours before being tested for germination under the optimum germination temperature for each species. In addition, physical scarification by cutting the seed coat was tested for breaking the seed dormancy. To assess the effectiveness of herbicides on the two *Prosopis* species under the greenhouse condictions, seeds of the two mesquite species were sown in plastic pots containing a mixture of 40% sand, 40% silt and 10% animal manure and kept until the 3-leaves stage. Pots were then arranged in a completely randomized design with six replicates. All herbicides were applied at three different doses (recommended dose = N, two-third dose = 2/3 N and half dose = ½ N) using a rechargeable backpack sprayer equipped with Teejet nozzles adjusted to a presture of 3 bars. On the 1, 3, 5, 7, 14, 21, 28 and 56 days after treatment, visual estimates for the percentage control and shoot height were recorded. At the end of the experiment, the biomass was determined on the harvested plants.

In addition, a field experiment were conducted at the Research Farm of Department of Agricultural Structures and Irrigation of Çukurova University to evaluate the efficacy of five different herbicides on dwarf mesquite. The experiment was laid out in a randomized complete block design with four replicates and the whole experiment was repeated twice during the consecutive summer seasons of 2017 and 2018. The treatments consisted of five herbicides (three doses each), a weed-free and a weedy check. Herbicide were applied when mesquite was at BBCH 33 development stage, in a spray volume of 300 l/ha using a motorized knapsack sprayer and estimates of percentage control and shoot height were recorded at 1, 3, 5, 7, 14, 21, 28, and 56 days after treatment. Plant biomass was obtained at the end of the experiment. To study the phenology of dwarf mesquite, a field experiment was performed in non-crop site where 100 dwarf mesquite plants of the previous season were selected randomly and their developmental growth stages were tracked in accordance with the BBCH coding system and the dates of all developmental events were recorded.

Results showed that the minimum, maximum and optimum temperature requirements for seed germination were 20°C, 30°C and 40°C for dwarf mesquite and 15°C, 35°C and 40°C for common mesquite, respectively. In the dormancy breaking experiments, treatments of pre-chilling at -5°C, pre-chilling at +5°C, preheating at 40°C, seed coat cutting and untreated control were resulted in 42%, 54%, 38%, 100% and 61% germination for dwarf mesquite and 55%, 70%, 83%, 100% and 70% for common mesquite, respectively. Indicating that the pre-chilling and preheating was adversely affecting the germination of dwarf mesquite while the seed coat cutting was significantly improved seed germination. In common mesquite case, the pre-chilling treatments was seemed to have a negative impact on seed germination, whereas the pre-heating has slightly broke the seed dormancy. In the two-year greenhouse experiment, all herbicides provided more than 90% control against the two *Prosopis* species. However, only 2,4-D tri-isopropylamine plus picloram provided 100% control of mesquite with its three application rates. In field studies, in contrast, except 2,4-D plus picloram, all herbicides have been shown to be ineffective against *P. farcta* at all application rates. Phenology experiment has shown that shoot growth of dwarf mesquite was started in May and reached the highest point by the end of May. However, flowering was begun in May and continued through July. One month after the end of flowering, fruits was formed and reached final sizes. In the first week of September, fruits were fully ripened. Shoot growth was declined through October and leaf fall began in October and lasted into the mid of December where the plant was entered into a senescence stage.

In conclusion, both of the mesquite species studied have shown to be tolerant to elevated temperature, with abilities to germinate in a wide range of environmental conditions. According to the study results, physical scarification was seemed to significantly promote mesquite seed germination, indicating that tillage and other physical practices might increase mesquite germination and invasion. Phenological studies show how important is the comprehensive understanding of plant growth and development in making management decisions. Field and greenhouse experiments indicated that herbicides might not be an effective or sustainable option for controlling mesquite shrubs. However, the study has also highlighted that the indigenous insect herbivores can influence the dwarf mesquite densities and are likely to offer a promising perspective to a better mesquite management.

GENİŞLETİLMİŞ ÖZET

Çeti, çok yıllık, çalı veya ağaç formunda, baklagiller familyasına bağlı olan en önemli istilacı yabancı otlardan biridir. *Prosopis* cinsi, yaklaşık 47 türden oluşmaktadır. Ancak, bu türlerinin %80'i Amerika kıtasına özgüdür. Uluslararası ulaşım ve insan hareketliliğinin artmasının bir sonucu olarak, birçok Çeti türü bilerek veya yanlışlıkla yeni bölgelere taşınmıştır. Günümüzde, Çeti, aşağı yukarı dünyadaki kurak ve yarı kurak bölgelerin çoğunda yayılan istilacı bir bitki haline gelmiştir. Bu çalışmada, Sudan'da istilacı yabancı ot olan *Prosopis juliflora* ve Türkiye'de sorun olan *Prosopis farcta*'nın biyolojisi ve mücadelesinin araştılması ve bu yabancı otlara karşı etkili bir mücadele stratejinin geliştirilmesinde bilimsel bir temel sağlanması hedeflenmiştir. Araştırmanın ana amaçları, (i) iki Çeti türüne ait tohumların çimlenmesi için sıcaklık gereksinimlerini belirlemek, (ii) bazı mekanik ve fiziksel işlemlerin, iki Çeti bitkisinin tohum dormansisi üzerindeki etkisini belirlemek (iii); sera ve tarla koşulları altında iki Çeti türünün üzerinde beş farklı herbisitin (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine ve 2,4-D triisopropylamine + picloram) etkinliğini incelemek; (iv) Çetinin biyolojik mücadelesine yönelik olarak, meyve veya tohum üzerinde beslenen herbivor böcek türlerini ve bunların Çeti'ye olan etkisini belirlemek; ve son olarak, (v) Çeti'nin fenolojik gelişme dönemlerini ortaya koymaktır.

Çimlenme denemeleri, *P. juliflora* ve *P. farcta* tohumlarının petri kaplarına yerleştirilerek, 5°C, 10°C, 15°C, 20°C, 25°C, 30°C, 35°C, 40°C ve 45°C sabit sıcaklıklarda laboratuar koşullarında yürütülmüştür. Daha sonra, çimlenme oranları, 28 günlük bir süre boyunca devam eden denemenin sonunda tespit edilerek, minimum, maksimum ve optimum çimlenme sıcaklıkları belirlenmiştir. İki Çeti türünün tohumlarındaki fiziksel dormansiyi kırmak amacıyla mekanik ve fiziksel işlemler olmak üzere farklı yöntemler uygulanmıştır. Tohumlar, -5°C ve +5°C'de ön üşütme, 40°C'de ön ısıtma ve embriyoya zarar vermeden tohum ucundan kesme olmak üzere dört farklı işleme tabi tutulduktan sonra her türün belirlenen optimum çimlenme sıcaklığında çimlenme oranı araştırılmıştır. Beş farklı herbisitin sera koşullarında iki Çeti türünün üzerindeki etkinliğini değerlendirmek için Çukurova Üniversitesi, Bitki Koruma Bölümü, Herboloji Laboratuvarına ait seralarda denemeler kurulmuştur. Denemelerde, iki Çeti türüne ait tohumlar, %40 kum, %40 silt ve %10 hayvan gübresi içeren toprak ile dolu plastik saksılara ekilmiştir. Denemeler, bölünmüş parseller deneme desenine göre, altı tekerrürlü olarak kurulmuş ve denemenin tamamı iki kez tekrarlanmıştır. Bitkiler üç yaprak dönemine geldiğinde, şarjlı pülverizatör kullanılarak, herbisiter uygulanmıştır. Herbisitler, önerilen doz (N), önerilen dozun üçte ikisi (2/3 N) ve önerilen dozun yarısı (1/2 N) olmak üzere üç farklı dozda uygulanmıştır. Uygulanan herbisitlerin Çetiye olan etkisi belirlemek için, deneme 1., 3., 5., 7., 14., 21., 28. ve 56. günlerde kontrol edilmiştir. Deneme boyunca, herbisitlerin bitkilerin üzerinde oluşturduğu zararlanma oranı yüzde olarak kaydedilmiş, bitki boyları ölçülmüştür. Deneme sonunda, bitkilerin toprak									üstü aksamı hasat edilip, yaş ve kuru ağırlıkları alınmıştır. Elde edilen veriler, herbisit uygulaması yapılmamış kontrol bitkileri ile karşılaştılarak etki ortaya konmuştur. Tarla denemeleri ise, Çukurova Üniversitesi, Tarımsal Yapılar ve Sulama Bölümünün Araştırma Çiftliği'nde gerçekleştirlmiştir. Denemeler, Çeti ile bulaşık ve mısır hasadı yapılmış olan bir tarlada, tesadüf blokları deneme desenine göre, dört tekerrürlü olarak iki kez yapılmıştır. Herbisitler, sera denemelerinde olduğu gibi üç farklı dozda, motorlu pülverizatör kullanılarak uygulanmıştır. Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie (BBCH) bitki kodlama skalasına göre Çetinin 33. gelişme döneminde (gövdenin tam uzunluğunun yaklaşık %30'unda iken) herbisitler uygulanmıştır. Denemeler, beş herbisit uygulaması (her herbisit için üç doz), yabancı otlu kontrol ve yabancı otsuz kontrol olmak üzere her blokta toplam 17 parselden oluşmuştur. Herbisitlerin Çetiye olan etkisi belirlemek için, herbisit uygulandıktan1, 3, 5, 7, 14, 21, 28 ve 56 gün sonra bitkiler görsel olarak kontrol edilip yabancı ot üzerindeki etkinliği (% olarak) kaydedilmiştir. Ayrıca, herbisitlerin Çeti bitkisinin gelişmesi üzerine etkisini belirlemek için aynı zaman periyodunda bitki boyu ölçülmüştür. Deneme sonunda, bitkilerin yeşil aksamı hasat edilmiş ve laboratuvarkoşullarında yaş ve kuru ağırlıkları alınmıştır.

Biyolojik mücadele çalışmaları, 2016'da Adana ilinde üç farklı lokasyondan toplanan Çeti (*P. farcta*) tohumları üzerinde yürütülmüştür. Bu lokasyonlardaki olgun bitkiler üzerinden 500 adet Çeti meyvesi toplanıp laboratuvara getirilmiştir. Meyvelerin içi açılıp, kontrol edilmeden önce zararlanmış ve sağlıklı meyve olarak iki gruba ayrılmış ve kumpas yardımıyla her meyvenin boyu ve eni ölçülmüştür. Daha sonra her meyvedeki erginlerin çıkış deliklerin sayısı kaydedilmiştir. Meyvede veya tohumda beslenen herbivor böcekleri saptamak amacıyla, laboratuvar koşullarında meyveler açılıp görsel olarak incelenmiştir. Bundan sonra, tohumlar sağlıklı, zararlanmış ve gelişmemiş tohum olmak üzere üç gruba ayrılmıştır. Her bir gruba dahil tohum sayısı kaydedilmiştir. Ayrıca, bulunan böcekler %70'lik alkol içeren plastik tüpler içerisine saklanıp, teşhise gönderilmiştir. Çetinin fenoloji çalışmaları, tarla koşullarında ve Adana ilinde yürütülmüştür. Kültür bitkisi yetiştirilmeyen bir alanda rastgele olarak 100 adet Çeti (*P. farcta*) bitkisi işaretlenmiştir. Seçilen bitkilerin gelişimsel büyüme aşamaları, BBCH kodlama sistemine göre belirlenmiş ve tüm gelişme dönemlerinin tarihleri gün ve ay olarak kaydedilmiştir.

Çalışma sonuçlarına göre, Çeti (*P. farcta*) tohumlarının çimlenmesi için minimum, maksimum ve optimum sıcaklık gereksinimleri sırasıyla 20°C, 30°C ve 40°C olduğu; ve *P. juliflora* için sırasıyla 15°C, 35°C ve 40°C olduğunu belirlenmiştir. Dormansi kırma denemelerinde, -5°C'de ön üşütme, +5°C'de ön üşütme, 40 °C'de ön ısıtma, tohum kesme ve hiçbir uygulama yapılmamış kontrol tohumlarında Çeti için sırayıla %42, %54, %38, %100 ve %61 çimlenme oranlarına neden olurken, Sudan Çetisinde (*P. juliflora*) sırayla %55, %70, %83, %100 ve %70 çimlenme oranlarına neden olduğunu belirlenmiştir. Ön üşütme ve ön ısıtma uygulamalarının Çeti (*P. farcta*) tohumlarının çimlenmesini olumsuz yönde etkilemiş iken, tohum kesmenin Çeti tohumlarının çimlenmesini önemli bir şekilde arttırdığı ortaya konulmuştur. Sudan Çetisine baktığımızda, ön üşütme işlemlerinin tohum çimlenmesinde önemli bir şekilde azalmaya neden olurken, ön ısıtma ise, tohum dormansisini az miktarda kırdığı tespit edilmiştir. Kimyasal mücadele denemelerinde, tüm herbisitlerin iki *Prosopis* türüne karşı %90'dan fazla kontrol sağladığı bulunmuştur. Ancak, sadece 2,4-D + picloram'ın üç uygulama dozu ile Çetiyi %100 oranında kontrol etmiştir. Tarlada yapılan kimyasal mücadele çalışmalarında ise, sera denemelerinin aksine, 2,4-D + picloram hariç, test edilen tüm herbisitlerin bütün uygulama dozlarının *P. farcta*'ya karşı etkisiz olduğu belirlenmiştir. Çeti (*P. farcta*)'nın fenolojik çalışmalarına göre, bitki ilk yapraklarını Mayıs ayında oluşturmaya başlamaktadır ve Mayıs ayının sonunda en yüksek noktaya ulaşmaktadır. Çiçeklenme dönemi, Mayıs ayında başlamakta ve Temmuz ayına kadar devam etmektedir. Çiçeklenme bittikten bir ay sonra meyveler oluşmaya başlamakta ve Ağustos ayının ortasına doğru meyveler son büyüklüğüne ulaşmaktadır. Eylül ayının ilk haftasında meyveler tamamen olgun hale gelmektedir. Ekim ayından itibaren sürgün büyümesi azalmakta ve yaprak dökümü başlamaktadır. Bu süreç Çetinin yaşlanma evresine girdiği Aralık ayının ortasına kadar sürmektedir.

Sonuç olarak, incelenen Çeti türlerinin her ikisi de yüksek sıcaklığa dayanıklı olup, geniş bir çimlenme aralığına sahiptir. Bu da beraberinde yüksek oranda çevresel toleransı getirmektedir. Ayrıca, fiziksel zararlanmanın Çeti tohumlarının çimlenmesini önemli ölçüde artırması, tarlada toprak işlemenin ve diğer fiziksel uygulamaların Çeti tohumlarını aşındırılarak, çimlenmesini ve yayılmasını artırabileceğini göstermektedir. Fenolojik çalışmalardan elde edilen sonuçlar, Çetinin büyüme ve gelişmesinin kapsamlı bir şekilde anlaşılması, Çeti ile başarılı ve etkili bir mücadele yapabilmek için son derece önemlidir. Özellikle tarla denemeleri bize göstermiştir ki, herbisitler tek başına yoğun Çeti popülasyonlarının mücadelesi için etkili veya sürdürülebilir bir seçenek olmayabilir. Bu nedenle, entegre mücadele kapsamında diğer mücadele yöntemleri de düşünülmelidir. Bunlardan birisi olan biyolojik mücadele önemli bir stratejidir. Dolayısıyla, Çeti türleri üzerinde beslenen herbivor böceklerin korunması ve doğada desteklenmesi ile birlikte Çetinin yoğunluğunun azaltılabileceği ümit veren bir perspektiftir.

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LIST OF ACRONYMS AND ABBREVIATIONS

2,4-D :	2,4-D amine
a.i. :	Active ingredient
DAT :	Days after treatment
GN :	Glufosinate (glufosinate ammonium)
LD_{50}	Leathal dose for 50% of the population
RS :	Roundup star (glyphosate potassium)
TD :	Touchdown (glyphosate diammonium)
TR :	Tordon (2,4-D tri-isopropylamine + picloram)
WAT :	Weeks after treatment
WD :	Weedy check
WF :	Weed-free check

XXXIX

1. INTRODUCTION

Mesquite is a flowering plant belonging to the genus *Prosopis*, which contains about 47 known species in the pea family, Fabaceae. They are most commonly found in the arid and semiarid regions of Western Asia, Africa and America (Burkart, 1976). The taxonomy of the genus *Prosopis* has already been subjected to several reviews by different authors and it still needs further research to facilitate comprehensive understanding of these weeds. The problem with mesquite identification results from the extreme variability among the species or between individual plants of the same species. The most comprehensive studies on the genus *Prosopis* L. were carried out by Burkart (1976). Mesquite is one of the worst invasive plant species that recently become a major threat to the agriculture and pasture lands in many parts of the world (Shackleton et al. 2014). The deep and the rapidly growing root system is the most widespread and important trait among all *Prosopis* species and many studies suggest that deep roots can forage for water and nutrient supplies totally beyond the reach of surface roots. Therefore, the root system of mesquite plays a central role in the cycling of nutrients and therefore seedling survival (Villagra et al. 2010).

The global increase in human mobility around the world has led to mass transportation of many plant species out of their native ranges. While in some cases new crops and ornamental plants have been introduced intentionally, in other cases, agricultural weeds have been accidentally introduced into new habitats (Mack, 2003). The deliberate introduction of mesquite in many regions around the world has been done for many reasons. In Africa and Asia, for instance, apart from forestation soil stabilization, the most outstanding reasons for mesquite introduction is provision of fuel, charcoal and firewood, construction materials for local communities (Pasiecznik et al. 2001; Witt, 2010; Wise et al. 2012). Favourable environmental conditions and absence of specialist natural enemies in the new habitats are the main factors that introduced plant become an invasive and often appear to be more competitive than native plants. With the lack of natural enemies, invaders allocate most of their resources to growth, reproduction and survival. In contrast, native plants continue battling their natural enemies through costly defensive traits plus competition with new weed neighbors that reduce their growth and seed production. The invasion of grasslands by mesquite leads to quantitative changes in species composition and abundance of plants and vertebrates (Kotliar, 2000; Royo and Baez, 2001), posing a real threat to biodiversity and ecosystems globally (Alpert et al. 2000). Today, the Sub-Saharan Africa is considered the most vulnerable region to the threat of invasive species (Paini et al. 2016). *P. juliflora* is declared as a major invasive weed species in Ethiopia, India, Kenya and South Africa, where in Sudan its eradication has been proposed (FAO, 2006; Australian Weed Committee, 2012; Low, 2012; Van Wilgen et al. 2012). The common mesquite (*P. juliflora*) is known to cause several socioeconomic, ecological and environmental problems on both agricultural and non-agricultural lands in their introduced ranges (Ahmed Elhouri, 1986; Elfadl, 1997; Elfadl and Luukkanen, 2003). In Sudan, the socioeconomic impacts of alien, invasive weed, *P. juliflora* are not well understood and yet, only few studies have investigated some aspects of mesquite invasion and management. Globally, tremendous efforts are being made to manage and control the invasive mesquite species, but, the majority of these efforts have failed to achieve the goal. In Australia and South Africa, for instance, biological control of mesquite using seed-feeding Bruchid species has been succeeded to some degree (Zimmermann et al. 2006; Downey, 2011; Van Klinken and Pichancourt, 2015). Biological control was successfully used in Australia and South Africa; however, there are also areas where 'natural enemies' are present but were not deliberately introduced, for example, (seed-feeding beetles-Coleoptera: Bruchidae) in Egypt and *Algarobis prosopis* in Sudan and Yemen (Delobel and Fediere 2002; Al-Shurai and Labrada 2006; Babiker 2006). In Yemen there is no available information confirming that the non-indigenous *A. prosopis* feeds on the native *Prosopis cineraria* (Al-Shurai and Labrada 2006). There are increasing concerns that introduced insects could affect less invasive *P. pallida* populations in areas that are utilized by local communities (Pasiecznik et al. 2004; Pasiecznik et al. 2006; Zachariades et al. 2011). Chemical control of mesquite is implemented in regions with isolated mesquite invasions, whereas control through utilization is applied in countries with vast areas invaded by mesquite such as Kenya, Ethiopia and Sudan (Pasiecznik et al. 2006).

The other mesquite species, dwarf mesquite (*P. farcta*) is a difficult to control perennial legume shrub, native to Asia and Middle East. The plant is a drought and salt tolerant, invades a large area in the southeastern part of Turkey and causes considerable losses in non-irrigated crops. The plant has been declared noxious weed in the United States and other regions worldwide (Holm et al. 1991; USDA, 2016). Although there was a scientific evidence of potential herbivore insects native to Turkey and feeding primarily on seeds of *P. farcta*, research on biological control of dwarf mesquite is very limited (Adam et al. 2017). Chemical control of dwarf mesquite, using different herbicides has been investigated, but, all these efforts have been challenged because of growth recovery where new sprouts appear from underground stems and roots. Dwarf mesquite was considered one of the most challenging invasive species because of its tolerance to high temperatures, humidity and salinity (Pasiecznik, 2004; Qasem, 2007). In Turkey, the plant is worryingly spreading in the southern part of the country infesting Adana, Mardin, Diyarbakır, Elazığ, Hatay, Mersin, Kahramanmaraş, Muş and Şanlıurfa Provinces, posing a serious threat to the productivity of agricultural and pasture lands (Yücel, 1994; Bükün et al. 1995). Dwarf mesquite in grass pastures, non-crop areas and vegetable fields can be controlled to some degree with systemic herbicides, mostly 2,4-D and glyphosate, which are often applied in combination with other chemically related active ingredients (Qasem, 2007). The biological and chemical control of this weed has been investigated by many researchers (Khoramabadi et al. 2016). Glyphosate-based formulations have been the predominately applied herbicides in the majority of chemical control studies. Yet, control of this weed is still challenging to land managers and crop producers. For example, one of the most important practical challenges currently facing herbicide use as the dominant tool in dwarf mesquite control is that the plant shoots arise from buds on underground roots or stems, and while many herbicides will kill the above ground parts, the plant will rapidly develop a new shoot from the underground portion. In Turkey, although dwarf mesquite is increasing its range and posing a serious threat to agriculture, there have been relatively few studies on its biological and/or chemical control (Akkuzu, 2012). However, there are some insects attacking the reproductive parts of this plant by penetrating the seed capsule and feeding on the endosperm as the main component of their diet (Sertkaya et al. 2005; Adam et al. 2017).

According to the mesquite problem mentioned above, we have chosen to investigate these two mesquite species primarily because they predominate large areas of fertile soils and become a major threat to the agriculture and natural ecosystems in Turkey (*P. farcta*) and Sudan (*P. juliflora*). Therefore, this research was aimed to achieve several objectives specifically (i) to determine the minimum, maximum and optimum temperature requirements for dwarf and common mesquite seed germination; (ii) to determine the effect of different mechanical and physical treatments on the physical dormancy of seeds of two mesquite species; (iii) to investigate the efficacy of five different herbicides namely; 2,4-D, glyphosate diammonium, glyphosate potassium, glufosinate ammonium and 2,4-D + picloram on two mesquite species under greenhouse conditions; (iv) to investigate the effectiveness of herbicides on dwarf mesquite under field conditions; (v) to determine the phenological development stages and seed production of dwarf mesquite; (vi) to investigate the effect of native herbivorous insects as biological control agents on seed production of dwarf mesquite.

2. LITERATURE REVIEW

2.1. Mesquite Biology, Ecology and Distribution

Harris (1960) carried out a study on the distribution of some plant species compared with soil types and climatic characteristics in deserts and steppe soils in Central and Northern Iraq. The study reported that toxicity due to salinity, limited aeration, difficulty in abstracting moisture and the mechanical difficulty of the roots forcing its way through dense soils are the most significant four possible causes for poor plant growth in the desert and steppe soils. Yet, dwarf mesquite has shown a high tolerance to all adverse climate conditions. At the same time, it has been determined that the penetration capabilities of the plant roots of dwarf mesquite (*P. farcta*) have reached a depth of 5 m below the ground. The plant also has an exceptional compaction tolerance, which could be due to the fact that it is the only deep rhizomatous species with ability to grow in in the dry season when the soils are least compacted. The author suggested that this is of great importance in selecting crops and trees to grow in soils subjected to gilgai and bad-structured conditions.

Habib et al. (1971) conducted a study on the determination of indicator plants in Iraq, and it has been reported that *P. farcta* has the ability to grow well in both saline and non-saline soils. As expected, halophytic communities were mostly found in the northern part of Iraq. According to the results of the study, *P. farcta* has been spread in almost all parts of the country and has a wide geographical distribution and ecological area coverage. In terms of climate and soil type, these plants can grow under different environmental conditions and have become a very common native plant species in Iraq. Although it is usually found in low salt and non-salty soils, it is also found in highly saline habitats. However, *P. farcta* plants are generally considered to be used as an indicator plants of less saline or non-saline soils.

Baazzaz (1973) studied seed germination in relation to salt concentration in three populations of *Prosopis farcta* by investigating the dwarf mesquite pods collected from three habitats which are environmentally different in terms of annual precipitation and soil salt content. In this study, the seeds were first germinated at various concentrations of sodium chloride (NaCl) and then germination, radicle growth and dark respiration were examined. The authors reported that the three populations showed different responses to NaCl, when the population collected from northern part showed significant sensitivity compared to the other populations. However, the results showed that there are inter-population differences in the effect of sodium chloride on seed germination, radicle growth and seedling respiration. It is also suggested that the three populations represent “salt ecotypes” of this shrub, which is widely distributed in Iraq. The researchers attributed the reasons for the wide spread of this shrub to the improper agricultural land use which created vast saline areas.

Iskenderoglu et al. (1993) studied the seed dormancy breaking of dwarf mesquite (*P. stephaniana*) among 20 weed species. The experiment was made up of untreated control, seed cutting, preheating at 30°C for one week, pre-chilling at 4°C ± 1, soaking in pure water for 24 hours and soaking in KNO_3 of 0.2% for 24h; then the seeds were transferred to germination incubators after being subjected to eight pre-treatments. Triphenyl tetrazolium chloride (TTC) test was applied to the non-germinating seeds until the end of the study. As a result, a statistically significant increase was observed in the germination percentage of *P. stephaniana* seeds, especially in seed cutting treatment compared to the control, followed by pre-chilling, airless environment and KNO_3 application. Optimum germination temperature for dwarf mesquite seeds was determined to be 25°C.

Bükün et al. (1995) investigated the biology, distribution and damage status of *Prosopis farcta* in the natural environment in Şanlıurfa province, Turkey. According to the results of the study, the distribution of *P. farcta* in Şalıurfa province has been in Akçakale, Birecik, Bozova, Halfeti and Suruç districts and have been found to be more intensive in the deep profile soils and especially on the roadsides. According to the morphological studies, *P. farcta* was found to be 45 - 50 cm in length, perennial plant, and it was said to be in the shrub form. At the same time, the roots of dwarf mesquite were 2.5-3 cm in diameter, hard and woody, and found to lie under the ground up to 70 m. The phenological study of *P. farcta* showed that the plant began to open the leaves from April and flower buds were formed about 10 days later. It began to bloom in late May and beginning of June, while the fruits were formed in late June and fully ripened in August. In addition, during the study, it was reported that the seed beetle *Caryedon palestinicus* Southgate (Coleoptera: Bruchidae), caused a loss of 67.34% on dwarf mesquite seeds.

Orel (1996) investigated the weeds that cause a reduction in the production of wheat and corn in Çukurova Region, it was reported that 127 weed species, in 28 plant families, which considered troublesome weeds in the region. In addition, the study results indicated that among the species encountered in the cultivated areas, there were some species that could be used as indicators of ecological factors such as height, relief, ground water, soil pH, limestone, salinity, organic matter, cation exchange capacity or texture. Additionally, it was determined that *P. farcta* was found among the weed species with a frequency of occurrence more than 10%.

Uygur et al. (1996) conducted a research to identify families and species of weeds infesting okra, tomato, bean, carrot, cucumber, pumpkin, watermelon, melon, cabbage, lettuce, eggplant, leek, onion and radish vegetable fields in the South Anatolian Region of Turkey and to investigate management opportunities for these weeds. As a result of the study, 72 weed species belonging to 27 plant families were identified and their frequency of occurrence, general area coverage and special area coverage were separately determined. Among these species, the frequency of occurrence of *P. farcta* was 46.59%. However, It was determined that

P.farcta was the fourth most common species among the five most common species in the South Anatolian region.

Gönen and Uygur (1998) investigated the effect of herbicides used for weed control in agricultural lands on the weed flora in Çukurova region. To determine the change in weed flora, the authors studied the frequency of occurrence and percentage coverage. The results of the first survey conducted in 1983 showed that the distribution of weeds and the number of species increased compared to the results of the second survey conducted in 1996. Among the investigated species, the frequency occurrence of *P. farcta* in 1983 was 62.86% and the percentage cover was 32.64%. In 1996, the frequency and percentage cover were found to be 68.85% and 3. 4%, respectively. In 1983, *P.farcta* was ranked third among the five most common species in Çukurova Region, and it was determined that it was first common weed species in 1996 in the same region.

Shirke (2001) studied leaf photosynthesis, dark respiration and fluorescence as influenced by leaf age in an evergreen tree*, Prosopis juliflora*. It was observed that 92% of CO_2 fixed per day was respired by the young leaves. The fluorescence response characteristics revealed that in all types of leaves there was a complete recovery of the photochemical efficiency at sunset. The young and old leaves were photosynthetically less efficient than the mature leaves. They were well adapted to the harsh environment.

Tursun et al. (2003) conducted a study to determine the weed species that cause real problems in sugar beet production areas in Kahramanmaras province, Turkey to determine their density. In this study, 54 sugar beet fields were sampled in Kahramanmaraş province. As a result, in the 2000-2001 growing seasons, 41 weed species belonging to 22 families, including 1 parasitic weed, 1 seedless, 2 monocotyledons and 18 dicotyledonous weeds were determined. The average density of *P. farcta* was 0.13 plant/m^2 in Kahramanmaraş province and 0.88 plant/m^2 in Pazarcık district.

Bükün (2005) carried out a study in Harran Plain in Şanlıurfa, after the irrigation system started in the region to determine the changes in the weed flora in the areas where continuous cotton cultivation took place in the last ten years. The results of the survey conducted in Sanliurfa province between 1995 and 1996 were compared with the results obtained from the second survey in 2004 in the same province in order to determine the distribution and density of weeds infesting cotton-growing fields. As a result of two surveys conducted between 1995 and 1996, 36 weed species belonging to 14 families were found. Among the species found, the frequency of *P. farcta* in 1995, 1996 and 2004 was 41.80%, 38.18% and 14.00%, respectively. Moreover, density of *P. farcta* was found to be 0.53, 0.93 and 0.40 plants/m^2, respectively. The *P. farcta*, which prefer arid lands, has been observed to have a significant decrease in the terms of frequency and density throughout the Harran Plain after the new irrigation system has started.

Üremiş (2005) conducted a study to determine the weed species in the olive orchards in Hatay province that includes Mediterranean climate which is hot and dry in summer and rainy in winter. In this study frequency and the density of the weeds were studied in 51 olive orchards during 2003 and 2004 seasons for winter weed surveys were carried out twice (April – May for winter weeds and August – September for summer weeds). As a result, a total of 92 weed species belonging to 29 families were identified. One-third of the total identified weed species were monocotyledonous, while the rest were dicotyledonous weeds. However, the families of Poaceae, Asteraceae and Fabaceae have been identified as the most common families in Hatay province. The most common species were *Glycyrrhiza glabna* L. (81.6%), *Sorghum halepense* (L.) Pers. (81.4%), *Convolvulus arvensis* L. (68.8%), *Portulaca oleracea* L. (76.1%), *Prosopis farcta* (Banks & Sol.) Macbride (69.7%).

Al-sherif (2007) carried out a study to investigate the effects of chemical scarification, salinity and preheating treatments on germination of *P. farcta* seeds as an initial step for the spread of *P. farcta* in the newly rehabilitated lands in the

Egyptian desert. Similar to those untreated controls, no seed germination took place when there was no chemical scarification. It was found that the moderate salinity (75 and 100 mM NaCl) had no effect on seed germination, whereas in the high salinity level (150 and 200 mM NaCl), seed germination percentage decreased to about 30% and 70%, respectively. Percent germination and vigour value, depending on the length of exposure period of sulfuric acid, were reported to be 100% for exposure periods of 15 min and 20 min respectively. The study approve that *P. farcta* has the biological ability to grow and develop in salt-affected soils, but its seeds need to be scarified.

Maundu et al. (2009) studied the impact of *P. juliflora* on Kenya's semiarid and arid ecosystems and local livelihoods. It is a small, fast-growing, drought-resistant evergreen tree of tropical American origin. Its pods are used as livestock food and are fed upon by native herbivores. It produces good timber and shade and keeps arid environments green. This is an attractive candidate for arid land environmental rehabilitation programs. *Prosopis* produces masses of pods containing small tough smooth seeds. When pods are eaten by livestock, seeds pass easily through the gut. Once in the soil, seeds can lie dormant for a long time, until good conditions return. *Prosopis* is deep-rooted. It has become highly invasive and is hard to control once established. A research was undertaken to determine the spread of *P. juliflora* over time in Kenya and its effect on livelihoods and biodiversity. It was more aggressive in arid lands of the north and formed thorny impenetrable thickets, especially alongside water courses, flood plains, roadsides and in inhabited areas. It encroached upon paths, dwellings, irrigation schemes, crop farms and pastureland, significantly affecting biological diversity and rural livelihoods. In all three sites, there was significantly more plant diversity outside a *Prosopis* thicket than within it. It was evident that, in areas where *Prosopis* was well established, it was beyond the community's ability to control its expansion. Despite the stand of the affected local communities, the environmentalists, scientists and development workers are still divided on *Prosopis* matters. It is evident that Kenya's vast arid and semiarid lands totaling 80% of land area are at risk and, the longer the wait, the more difficult it will be to control or eradicate the species. A comprehensive policy on *Prosopis* was proposed.

Ramezani et al. (2010) investigated the effect of mechanical scarification (seed cutting) and chemical pre-treatments such as H_2SO_4, HCI, $CaSo_4$, HNO_3, NaCI, K2SO$_4$, NaOH and $CaCI_2$ on seed germination of *P. farcta*. The results indicated that the dwarf mesquite seed dormancy was mainly depend on the physical structure of the seed coat. Because more than 80% of seeds were germinated only two days after cutting the seed coat. Seed cutting achieved the highest seed germination percentage (89.33%) comparing to chemical treatments. Seeds pre-treated with different acids showed that destruction of seed coat would successfully enhance the germination process. In chemical treatments, the maximum germination percentage of 57.33% was observed when seeds were pretreated with H_2SO_4 for 10 minutes.

Akkuzu et al. (2012) conducted a study on germination biology, dormancy breaking and chemical control of dwarf mesquite. Germination studies were carried out in laboratory conditions where seeds were subjected to three constant temperatures (20, 25 and 30 ° C) and different dormancy breaking methods (preheating, pre-chilling, H_2SO_4, KNO_3, soaking in pure water, seed coat cutting, and mechanical scarification) were applied. According to study results, the optimum temperature for seed germination were 30 and 35 °C, while the most effective method for dormancy breaking were found to be seed coat cutting, H_2SO_4 and KNO_3 treatments.

Alebrahim et al. (2013) studied the effect of some mechanical (scarification with sandpaper and scalpel) Chemical (sulfuric acid and sodium hydroxide) and physical (boiling water) treatments on breaking seed dormancy of two populations of dwarf mesquite (*P. farcta*), which is considered a troublesome invasive weed in arid and semi-arid regions in Iran. Germination obtained in mechanical, chemical and physical treatments for two populations were (89% and 68.2%), (72.8% and

54.2%) and (53.6% and 28%) respectively. Interestingly, sodium hydroxide and physical scarification showed the least effect on dwarf mesquite seeds in both populations. In addition, seed hardness was considerably different between the two locations.

Kumar and Mathur (2014) studied the impacts of invasion of a ligneous *P. juliflora*, in plant communities of reserve forests, protected forests, unprotected forests and open grazing lands in Jamnagar district in arid coastal areas of Gujarat state, India. Sites invaded by *P. juliflora* had a different ligneous plant composition. In all land uses, *Prosopis*-invaded sites showed more species richness, diversity and evenness. However, the increase in species richness was due to the occurrence of more weedy species along with *P. juliflora.* Even amongst the protected and undisturbed sites, the dominance of late successional species, that is *Acacia senegal, Maytenus emarginata, Zizyphus nummularia* and *A. nilotica*, was less at sites with *P. juliflora* than at sites without it. The density of *Commiphora wightii*, an endangered species, was decreased with increasing density of *P. juliflora.* Invasion of *P. juliflora* had shown demonstrable adverse impacts on plant communities in arid grazing lands.

Gichua (2014) was studied the negative impacts of *P. juliflora* on aspects of biodiversity and selected habitat conditions in Baringo, Kenya. The plant was reported as a highly invasive species in Kenya. In this study, four hypotheses were tested to explain the effects of the invasion of *P. juliflora* on soil nutrient status, diversity of indigenous plant species, diversity of floral insect visitors of native *Acacia* spp., and plant and soil analysis revealed that the *P. juliflora* density had a significant influence on total organic carbon and pH, and had a negative effect on overall native plant species richness and density of *Acacia* species. This revealed clearly that *P. juliflora* has an effect on the species richness of local species, whereby *P. juliflora* is slowly replacing the indigenous species. The results showed that *P. juliflora* is a preferred source of floral resources by bees, *Apis mellifera*, during the dry season. Allozyme analysis revealed minimal genetic distance between populations. This study shows that the invasive species have negative consequences for the local ecosystem at high densities.

Abbas et al. (2018) studied the effect of camel ingestion on survival, viability and germination of *P. juliflora* seeds through endozoochory mechanism. In this study, four adult camels were fed with mesquite seeds and their dugs were collected, dried and crushed. Length, width and height of retrieved seeds were measured. Afterwards, seeds were tested for germination. As a result, most of the seeds were retrieved 24 to 48 h after ingestion. Retrieved seeds were significantly longer, wider, higher, with larger volume relative to control seeds. Passage through digestive system was found to significantly increase germination ratio.

2.2. Management of Mesquite Species

Belinsky and Kugler (1978) investigated the biology and host preference of *Caryedon serratus* subsp. palaestinicus Southgate (Coleoptera: Bruchidae) under two different laboratory conditions (25°C; 50% RH and 30°C ; 70% RH) in Israel. In the opposition preference tests, *Caryedon serratus* was found to prefer *P. farcta* seeds more favorably than the seeds of the peanut (*Arachis hypogea*). Furthermore, when the peanut is presented alone, *Caryedon serratus* it lays eggs but the development of the larvae was seemed to be considerably longer than in the seeds of *P. farcta*.

Jacoby et al. (1981) conducted a study on chemical control of honey mesquite (*P. juliflora* var. *glandulosa*) in field condition using 3,6-Dichloropicolinic acid, which formulated as monoethanolamine salt containing 1.75 kg/L active ingredient. The research was lasted in three years in two locations in Texas and herbicide was applied at a volume of 9.36 L/ha on honey mesquite at full leaf maturity. Additionally, triclopyr and 2,4,5-T plus picloram were applied as control herbicides. Herbicide application was done in May and June and evaluated through October and November of the 2nd and 3rd year after treatment to assess the final efficacy of herbicides. As a result, 3-yr-post treatments evaluations showed 3,6-Dichlorocolinic acid to be significantly ($P<0.05$) more effective against honey mesquite than other herbicides. In the two locations 3,6-Dichlorocolinic acid provided 60% and 68% mesquite mortality, followed by 2,4,5-T plus picloram. However, lowest mesquite control was found in 2,4,5-T and 2,4,5-T plus dicamba treatments.

Yücel (1994) observed a wide spread of dwarf mesquite (*P. facta*) in the Şanlıurfa province in the Southeastern Anatolia region of Turkey and reported a new insect species feeds on the seeds of this weed. In the study, it was mentioned that this weed has been a real problem in the agricultural lands, and that it was drought resistant and deep rooted plant. In addition, *Caryedon palestinicus* Southgate (Coleoptera: Bruchidae) species have been reported as a native biological agent feeding on *P. farcta* seeds, which caused major changes in the agricultural structure of this region.

Uygur et al. (1995) carried out a study between 1992 and 1994 in order to determine the diversity and distribution of weed species in the field and roadside areas of Çukurova Region. In this study, 142 species belonging to 30 families were determined by sampling from 216 different locations. Most of the identified weeds were members of Asteraceae, Poaceae and Fabaceae families. According to this study results, bermudagrass (*Cynodon dactylon*) and *P. farcta* were found to be the most important weeds in the fields and roadsides.

Mennan and Işık (2003) investigated the invasive weed species in onion production areas in Amasya province, Turkey. In this study, two surveys were carried out between 1997 and 1999-2000 in order to present the effect of invasive weed species and agricultural practices on the composition of weed flora in Amasya foreign. The frequency of occurrence of weeds (%) and weed density in the square meter were determined in survey studies and the results obtained from the first and second surveys were compared. As a result, in the first survey conducted in 1997, only 23 weed species were found, while 87 weed species were found in the second survey conducted in 1999-2000. Among the invasive weed species investigated, the frequency of *P. farcta* was found to be less than 5% and its density (plant / m2) was below the 0.04 in 1997, while the frequency and density in the square meter in the second survey in 1999-2000 were 11.6% and 0.25 respectively. According to the results of the study, application of the same weed control methods, fertilization, crop rotation and the use of seeds mixed with weed seeds has been found to cause a great change in the weed composition.

Sertkaya et al. (2005) studied the effect of the seed beetle *Caryedon palaestinicus* (Coleoptera: Bruchidae), as a biological control agent on seeds of *P. farcta*, which considered a common weed that causes serious problems on cultivated and non-crop lands in Turkey's Mediterranean and southeast region of Anatolia. In this study, in order to investigate the damage rate of *P. farcta* seeds caused by *C. palaestinicus*, 1000 *P. farcta* pods were collected from Antakya, Hassa and Kırıkhan in 2000 and the same number was collected in 2001 from Altınözü, Kumlu and Reyhanlı regions in September and October of each year. The collected seeds were examined every year in July and the number of adult seed beetles, the larva of the parasitoid *Rhaconotus major*, and the total number of damaged pods and seeds were recorded. As a result, the percentage of damage in Antakya, Hassa, and Kırıkhan was found to be 35.4%, 34.9% and 37.8%, respectively, while this ratio was 27.9%, 37.2% and 38.0% in Altınözü, Kumlu, and Reyhanlı districts respectively. In addition, *Rhaconotus major* (Hymenoptera, Braconidae) was found to live as a larval parasitoid on the *C. palaestinicus* in the survey area. Therefore, it was concluded that seed beetle (*C. palaestinicus*) is not a promising biological control agent for the management of dwarf mesquite under field conditions.

Berhanu and Tesfaye (2006) performed a study on the impact of *P. juliflora*, a multipurpose leguminous species introduc According to the mesquite problem mentioned above, we have chosen to investigate these two mesquite species primarily because they predominate large areas of fertile soils and become a major threat to the agriculture and natural ecosystems in Turkey (*P. farcta*) and Sudan (*P. juliflora*). ed into north-east Ethiopia. The study aimed to assess the uses and negative impacts of *Prosopis* and to evaluate the mechanical control and prescribed burning as management strategies. Various participatory rural appraisal (PRA) techniques were employed to collect ethno-botanical information on the uses of this plant. *Prosopis* is used for firewood, charcoal, forage, fencing, windbreaks and other purposes. Mechanical control (manual clearance and using bulldozers) was found to be effective when followed by proper soil management systems.

Qasem (2007) conducted a research during 1998/ 1999 growing season on chemical control of dwarf mesquite (*P. farcta*), which dominating an important part of productive agricultural land in the Jordan Valley, using different herbicides. *P. farcta* was considered tolerant to a wide variety of traditional weed management techniques such as soil solarization and mechanical methods. In this study, different herbicides including glyphosate, mecoprop, 2,4-D amine and ester, trichlopyr, paraquat, oxyfluorfen, bromoxynil and MCPA were applied in two filed experiments as individual treatments, mixtures and sequences. According to the results, except bromoxynil/MCPA mixture, all herbicide treatments achieved a considerable reduction in dwarf mesquite growth. Among all other herbicides, trichlopyr, 2,4-D ester, glyphosate and paraquat were effectively prevented plant recovery. The study suggested that only two or more applications of some of the examined herbicides such as trichlopyr, 2,4-D ester and glyphosate could effectively control the dwarf mesquite populations during a fallow period.

Teague et al. (2008) used an ecological economic simulation model to investigate the effect of fire and grazing on mesquite (*P. glanulosa* Var. *glandulosa*) and cactus (*Opuntia* spp.), which posing a serious threat to ecosystem health in Texas rangelands. In this study, investigators evaluated the biological and economic implications of fire and grazing methods over 30-year time. As a result, they found that in untreated cactus areas, the plant had a negative impact on range condition. In contrast, simulated burning treatments had a positive impact on range condition, in terms of productivity and profitability.

Akkuzu (2012) studied chemical control of dwarf mesquite in Adana province, Turkey. In this study, four glyphosate-based formulations namely, 424 g/l glyphosate diammonium salt, 441 g/l glyphosate potassium salt, 607 g/l glyphosate isopropylamine salt and 480 g/l glyphosate isopropylamine salt; and 500 g/l 2,4-D amine were, except 2.4-D, applied in two doses on dwarf mesquite under field conditions. As a result, 607 g/l glyphosate isopropylamine salt, 424 g/l glyphosate diammonium salt, 441 g/l glyphosate potassium salt and 2,4-D amine showed the most effective control of dwarf mesquite.

Azab (2018) has investigated the potential of aqueous extract of *Carya illinoinensis* as a possible biocontrol agent against *P. farcta* in the USA. According to study results, relative to untreated controls, plants treated with *C. illinoinensis* have shown slight response as some branches were found to be dry. However, the effect of this extract was considered very poor and further research has been suggested.

3. MATERIALS AND METHODS

3.1. Materials

The main materials used in this research were the two mesquite species (seeds and plants) and five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate, 2,4-D amine and 2,4-D triisopropylamine+picloram). Moreover, there were many tools and equipment utilized during the laboratory, greenhouse and field experiments. Detailed information about these materials and equipment were given in this chapter.

3.1.1. The Two Mesquite Species Used in this Research

The dwarf mesquite (*P. farcta*) and common mesquite (*P. juliflora*) plant were used as major materials throughout this research. Mainly the seeds of these plants were used during the germination, dormancy breaking, and chemical control experiments. The morphological description of these plants, their biology, ecology and invasion were provided in the sections below.

3.1.1.1. Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.] Plant

Prosopis farcta of the family Fabaceae is a woody, broad-leaved perennial shrub of Irano-Turanian origin with extensions into the Mediterranean and Saharo-Arabian territories (Zohary, 1972). In recent years, widespread of the plant has been reported in the Middle East, Cyprus, Turkey, the Ukraine and North Africa (Pasiecznik et al., 2004). In Turkey, the plant has frequently reported among the most common weed species generally distributed in non-irrigated agricultural lands across the south eastern part of the Mediterranean region of the country (Yücel, 1994; Bükün et al., 1995). Dwarf mesquite is usually grow to 30 – 100 cm in height. However, in some cases, it may grows up to 2 m high depending on the habitat and many other factors. The plant has many different synonyms including: (i) *Prosopis stephaniana*; (ii) *Mimosa farcta*; and (iii) *Lagonychium stephanianum*. Morphologically, the plant develops gradually from a single-stemmed shoot in the juvenile stage to a multi-stemmed shoot in the adult stage with a very well-established root system which extend as deep as 30 metres to reach underground water bodies (Gile et al., 1997; Snyder and Williams, 2003). Nevertheless, the species still not classified as halophyte (Zohary, 1962). The deep roots and strong rhizome system are of great importance for the *P. farcta* to ensure enough water and nutrient intake from deeper soil layers. The stem is lightly hard, dense, durable and thorny. Leaves are dark green in colour, bipinnate, with many pairs of pinae, each pinna bearing 8 – 12 pairs of small oblong leaflets; in an opposite arrangement along the rachis. Flowers cylindrically clustered at a raceme or compound inflorescence bearing more than 50 small yellow flowers arranged circularly around the main axis. The fruit is an oblong pod, about 3 cm long and about 1.9 cm wide, and green, becoming dark brown when ripe. Each pods containing about 3 – 15 (8 in average) tiny, dark brown seeds. Closed pods stay attached to the twigs for at least several months before dropping. However, seed dispersal is relatively slow due to the fact that pods do not split spontaneously unless they are physically damaged or consumed by animals (Pasiecznik et al., 2004; Qasem, 2007).

Figure 3.1. Dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] infestation in Çukurova University, Department of Plant Protection Experimental Research Farm.

Dwarf mesquite reproduces both sexually via seeds and asexually through vegetative parts of root sprouts or adventitious roots. Therefore, the plant is considered “continuous” weed species that its foliage naturally dies in winter and sprout from the top in spring months. It shows itself to be a very well adapted to many adverse environmental conditions such as high humidity, drought, warm weather and moderate salinity. In addition, dwarf mesquite has extreme seed durability, long-term dormancy and low germination rate. These features together make it difficult to control through a variety of control methods (Tran, 2015). As an initial step, the present study aimed to determine the most effective herbicides and to assess the potential biological agents available in Adana region and their potential to reduce weed invasion.

3.1.1.2. Common Mesquite [*Prosopis juliflora* (Sw.) DC.] Seeds

Common mesquite is a shrub or small tree in the family *Fabaceae* native to South and North America (CABI, 2017). The plant was intentionally and/or accidentally introduced to many arid and semi-arid parts of Africa, Asia, Australia and many other regions (Burkart, 1976; Choge, et al., 2012). Like many other mesquite species, *Prosopis juliflora* is a resilient plant, tolerant to adverse environmental conditions including severe drought, high temperatures, low fertility, high salinity and low pH levels (Villagra, 1997). In many countries mesquite has intensively established, naturalized and eventually declared an invasive weed. In Sudan, it was introduced in 1917 (Brown and Massey, 1929; El Fadl, 1997).

3.1.2. The Herbicides used in the Chemical Control Studies

Five different herbicides namely; 2,4-D amine, glufosinate ammonium, glyphosate diammonium, glyphosate potassium and 2,4-D plus picloram, were obtained in their commercial formulations from different local pesticide suppliers in Turkey. Throughout the study, the herbicides were kept in an appropriate storage area. General information about the herbicides including their formulation, dosage, uses, selectivity, chemical structure, and mode of action were provided in this section.

3.1.2.1. Chemical and Biological Characteristics of Glyphosate Diammonium

Glyphosate was discovered and developed by Monsanto Chemical Company. The active ingredient in glyphosate, *N*-(phosphonomethyl) glycine, is a derivative of the amino acid glycine and phosphonic acid. In 1964, Stauffer Chemical Company developed several phosphonic and phosphinic acids to be used as industrial cleaners. In 1969 and 1971, Monsanto patented a couple of phosphonic acids as growth regulators and selective herbicides. Afterwards, Monsanto received a patent for the use of phosphonic acid derivatives as non-selective herbicides in 1974. In the early 1980s, the related herbicide, sulfosate, which is now sometimes known as glyphosate-trimesium (trimethylsulfonium salt) was released by the Stauffer Chemical Company. The herbicide was derived from the same parent acid, *N*-(phosphonomethyl) glycine. Currently, both herbicides are widely sold in the United States.

Use and Selectivity: The different salts of glyphosate are basically nonselective post-emergence herbicides to control a wide range of annual and perennial weeds. Glyphosate is a soluble liquid concentrate (SL) with a molecular formula of ($C_3H_6NO_5$ P_2 (NH_4). The herbicide is now sold under many different trade names for use in a variety of cropping and non-cropped situations. These various products are applied mainly on citruses, olives and vineyard crops and are effective on most herbaceous annual and perennial weeds (Table 3.1) at doses ranging from 0.56 to 1.12 kg a.i./ha. In general, the control of herbaceous perennials, perennial vines and woody species requires higher application rates. Because glyphosate is normally non-selective, selectivity has often been provided by application method and time, for example, glyphosate can be applied as a pre-planting or pre-emergence herbicide to control existing weeds in no-till farming systems and for turf-grass regrowth, where existing turf-grass must be controlled before reseeding, sprigging, or sodding processes. Glyphosate is also used as a post-harvest herbicide or during the off-season to manage certain perennial weed species. For instance, glyphosate is widely used to effectively control Johnsongrass in corn, grain sorghum, or cotton-growing fields when applied during late summer or fall months after the harvest of these crops. In some cases, glyphosate has been successfully applied as a harvest assistant. Some selectivity may be achieved by adjusting doses and application timing, as has been carried out with alfalfa and broad-bean crops. Modern herbicide application equipment such as the rope wicks and other wiper-type applicators, selective placement recirculating-sprayers, and, most recently, hooded-boomed sprayers have allowed the selective use of these otherwise non-selective herbicides. Glyphosate is also successfully used for spot treatment, in many non-crop sites and forests as an alternative option to hand weeding, to control many weed species. Some of the most substantial developments in the use of these herbicides have taken place in the last five years; for example, through the application of bio-engineering, several glyphosate-tolerant crops have been developed. This technology has produced crops such as soybean, cotton, corn, and canola with great tolerance to glyphosate at doses that are normally control a wide range of weed species infest these crops.

Mode of action: The first visible symptom after glyphosate application is growth inhibition, followed by a detectable yellowing (chlorosis) of treated plant parts. Symptoms are developing slowly, and when there are cool and cloudy climate conditions after treatment, symptoms develop at a quite slower rate. Five to ten DAT, the chlorosis turns into necrosis and the plants begin to die. Glyphosate translocates both via xylem and phloem; however, phloem translocation is not as common as in many other phloem-mobile herbicides. This lower movement of glyphosate is thought to be due to the fact that glyphosate is less well trapped in the phloem during movement of the sap through the phloem than weak acid herbicides, such as 2,4-D. Other research showed that the levels of shikimate acid were significantly increased in glyphosate-treated tissues. Shikimate accumulation was shown to be due to glyphosate inhibiting the chloroplastic enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS). EPSPS is the penultimate enzyme in the aromatic amino acid biosynthetic pathway that occurs in the chloroplast and its basic function is to convert the shikimate-3-phosphate (S-3-P) into enolpyruvylshikimate-3-phosphate (EPSP) and eventually leads to the production of the amino acids phenylalanine, tyrosine, and tryptophan (Amrhein et al., 1980). Shikimate accumulates in glyphosate-treated plant tissues; and the reason is that the shikimate-3-phosfate cannot be converted to the EPSP, and because the shikimate-3-phosphate is unstable, it is rapidly converted to the more stable form, shikimate.

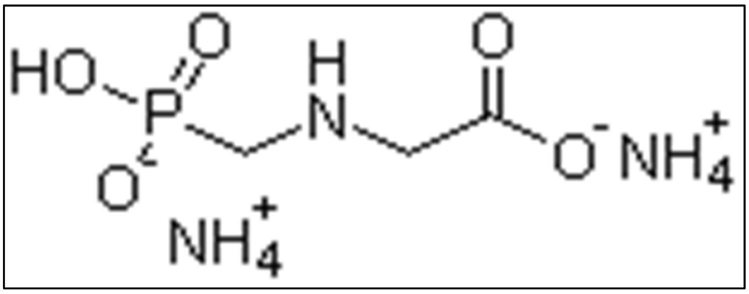

Figure 3.2. Chemical structure of glyphosate diammonium herbicide (Anonymous, 2019a).

Table 3.1. The Weed Species, Crops and Recommended Doses of herbicice containing Glyphosate Diammonium Salt in Turkey (Anonymous, 2018)

Crops/Situations	Weed species	Doses (g a.i. ha^{-1})
Citruses	Tumble pigweed (*Amaranthus albus* L.) Common cocklebur (*Xanthium strumarium* L.) Common purslane (*Portulaca oleracea* L.) Common lambsquarter (*Chenopodium album* L.) Barnyardgrass [*Echinochloa crus-galli* (L.) P.B.]	2120
	Johnsongrass (*Sorghum halepense* L.)	2544
	Quackgrass [*Agropyron repens* (L.) P. B.] Field bindweed (*Convolvulus arvensis* L.) Purple nutsedge (*Cyperus rotundus* L.) Common mallow (*Malva neglecta* L.)	3392
Olives	Redroot pigweed (*Amaranthus retroflexus* L.) Common lambsquarter (*Chenopodium album* L.) Barnyardgrass [*Echinochloa crus-galli* (L.) P.B.] Giradol [*Chrozophora tinctoria* (L.) Rafin.] Puncturevine (*Tribulus terrestris* L.)	1696
	Common cocklebur (*Xanthium strumarium* L.) Johnsongrass [*Sorghum halepense* (L.) Pers.]	2120
	Squirting cucumber [*Ecballium elaterium* (L.) A.Rich.]	2544
	Bermuda grass [*Cynodon dactylon* (L.) Pers.] Field bindweed (*Convolvulus arvensis* L.)	3392
Vineyards	Common lambsquarter (*Chenopodium album* L.) Common cocklebur (*Xanthium strumarium* L.)	2120
	Johnsongrass [*Sorghum halepense* (L.) Pers.] Redroot pigweed (*Amaranthus retroflexus* L.)	2544
	Bermuda grass [*Cynodon dactylon* (L.) Pers.] Field bindweed (*Convolvulus arvensis* L.) Common barnyardgrass (*Echinochloa crus-galli* L.)	3392

3.1.2.2. Chemical and Biological Characteristics of Glyphosate Potassium

Chemical structure: As shown in Fig. 3.7.

Applied on: Citruses, vineyards, hazelnuts and olive

Target Weeds: As shown in table 3.2.

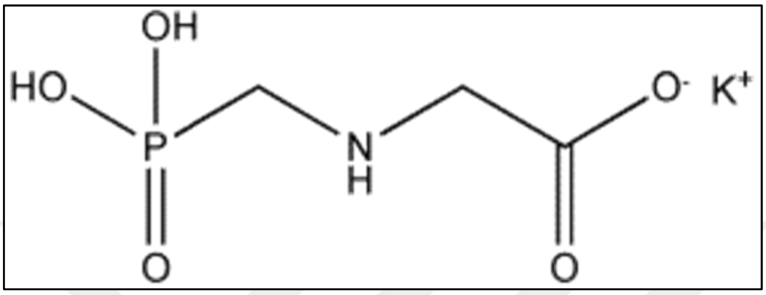

Figure 3.3. Chemical structure of glyphosate potassium salt (Glycine, N-(phosphonomethyl)-, potassium salt (Anonymous, 2019a).

Table 3.2. The Target Weed Species, Crops and Recommended Doses of herbicide containing Glyphosate Potassium in Turkey (Anonymous, 2018)

Crops/ Situations	**Weed species**	**Dose (g a.i. ha^{-1})**
Citruses	Black grass (*Alopecurus myosuroides* L.)	
	Tumble pigweed (*Amaranthus albus* L.)	
Vineyard	Smooth pigweed (*Amaranthus hybridus* L.)	
	Redroot pigweed (*Amaranthus retroflexus*)	
Hazelnut	Scarlet pimpernel (*Anagallis arvensis* L.)	
	Blue pimpernel (*Anagallis caerulea* L.)	
Olive	Sterile oat (*Avena sterilis* L.)	
	Yellow weed (*Boreava orientalis* Jaub & Spach)	1323
	Sterile brome (*Bromus sterilis* L.)	
	Downy brome (*Bromus tectorum* L.)	
	Shepherd's purse (*Capsella bursa-pastoris*)	
	Yellow star-thistle (*Centaurea solstitialis* L.)	
	Common lambsquarter (*Chenopodium album* L.)	
	Nettle-leaved goosefoot (*Chenopodium murale* L.)	
	Horseweed (*Conyza canadensis* L.)	
	Stinking hawksbeard (*Crepis foetida* L.)	
	Purple nutsedge (*Cyperus rotundus* L.)	
	Jimsonweed (*Datura stramonium* L.)	
	Flixweed (*Descurainia sophia* L.)	
	Hairy crabgrass (*Digitaria sanguinalis* L.)	
	Barnyard grass (*Echinochloa crus-galli* L.)	
	Square stalked willow herb (*Epilobium tetragonum* L.)	

	Common stork's bill (*Erodium cicutarium* L.) Sun spurge (*Euphorbia helioscopia* L.) Petty spurge (*Euphorbia stricta* L.) Common fumitory (*Fumaria officinalis* L.) Fineleaf fumitory (*Fumaria parviflora* L.) Cleavers (*Galium aparine* L.) Cut-leaved crans's bill (*Geranium dissectum* L.) European heliotrope (*Heliotropium europaeum* L.) Ox-tongue (*Helminthotheca echioides* L.) Wall barley (*Hordeum murinum* L.) Prickly lettuce (*Lactuca serriola* L.) Henbit dead-nettle (*Lamium amplexsicaule* L.) Dead-nettle (*Lamium macrodon* L.) Nipplewort (*Lapsana communis* L.) (*Lathyrus aphaca* L.) Burclover (*Medicago minima* L.) Round fuited-medick (*Medicago orbicularis* L.) Yellow sweetclover (*Melilotus indica* L.) Pennyroyal (*Mentha pulegium* L.) Annual mercury (*Mercurialis annua* L.) Ball mustard (*Neslia apiculata* L.) Ball mustard (*Neslia paniculata* L.) Common poppy (*Papaver rhoeas* L.) Rough meadow-grass (*Poa trivalis* L.) Prostrate knotgrass (*Polygonum aviculare* L.) Common purslane (*Portulaca oleracea* L.) Turnipweed (*Rapistrum rugosum* L.) Curly dock (*Rumex crispus* L.) Shepherd's needle (*Scandix pecten-veneris* L.) Groundsel (*Senecio vulgaris* L.) Hooked bristlegrass (*Setaria verticillata* L.) Wild mustard (*Sinapis arvensis* L.) Tall tumble mustard (*Sisymbrium altissimum* L.) Black nightshade (*Solanum nigrum* L.) Field sowthistle (*Sonchus arvensis* L.) Spiny sowthistle (*Sonchus asper* L.) Common sowthistle (*Sonchus oleraceus* L.) Johnson grass (*Sorghum halepense* L.) Goatsbeard (*Tragopogon aureus* L.) Puncturevine (*Tribulus terrestris* L.) Red clover (*Trifolium pratense* L.) Small nettle (*Urtica urens* L.) (*Wiedemannia orientalis* L.) Common cocklebur (*Xanthium strumarium* L.), Vaccaria (*Vaccaria pyramidata* L.), Ivy-leaved speedwell (*Veronica hederifolia* L.)	
	Camelthorn (*Alhagi pseudalhagi* L.)	

	Common mugwort (*Artemisia vulgaris* L.) (*Astrodaucus orientalis* L.) Plymouth thistle (*Carduus pycnocephalus* L.) Field bindweed (*Convolvulus arvensis* L.) Swallowworts (*Cynanchum acutum* L.) Bermuda grass (*Cynodon dactylon* L.) Licorice (*Glycyrrhiza glabra* L.) Steudel's morning glory (*Ipomea stolonifera* L.), Common gromwell (*Lithospermum officinale* L.), Creeping jenny (*Lysimachia nummularia* L.), Small-flowered mallow (*Malva parviflora* L.), Common mallow (*Malva sylvestris* L.), Spearmint (*Mentha spicata* L.), Water-dropwort (*Oenanthe silaifolia* L.), Bramble (*Rubus canescens* L.)	2646

3.1.2.3. Chemical and Biological Characteristics of Glufosinate Ammonium

Glufosinate (2-amino-4-(hydroxymethylphosphinyl)butanoic acid) is a white to light yellow crystalline powder with a solubility of 1,370,000 mg/l (ppm), a Hg vapor pressure of 0 mm at 25°C, and a soil half-life of 7 days. It is a foliar applied and has relatively no soil activity.

Uses: Glufosinate is formulated as a soluble liquid (SL) and sold under many trade names to be used in orchards and non-cropped areas. The glufosinate ammonium is non-selective and active only when applied as a post-emergence herbicide, with best activity on annual weeds and control of the above ground foliage of perennial weeds. Xylem and phloem translocation are not common, therefore accurate and precise spray cover is important for successful control of target weed species. The symptoms results from glufosinate application include chlorosis, which is then followed by necrosis, usually beginning to develop within three to five DAT. These symptoms are slightly like those provided by the membrane-disrupting herbicides such as dipheny-lethers and paraquat. However, the rapidity of membrane disruption (necrosis) is slower than that achieved by other herbicides with a direct membrane disruption mechanism of action (e.g., paraquat). If treated plants are transferred to a dark medium immediately after treatment, symptoms develop, but at a significantly decreased rate. Although glufosinate is the most widely used name of the synthesized herbicide, the common name which overwhelmingly used in the literature for the chemical structure is phosphinothricin (PPT). Glufosinate is a mixture of the D- and L- isomers of phosphinothricin, but only the L-isomer is active.

Mode of Action: Glufosinate is known to directly inhibit the glutamine synthetase (GS) enzyme in the nitrogen-assimilation pathway of higher plants. Glutamine synthetase is an enzyme that responsible for converting glutamate + ammonia into glutamine. Glufosinate competes with glutamate for binding to the GS enzyme, and when bind to the GS, glufosinate successfully blocks the GS enzyme from forming glutamine. Glufosinate inhibition of glutamine synthetase leads to reduced levels of glutamine, which in turn cause decreased levels of several other essential plant amino acids (e.g., glutamate, aspartate, asparagine, alanine, and serine), whose final synthesis depends on the existence of glutamine. After glufosinate treatment, levels of ammonia in plant leaves, which are generally very low, rise dramatically and within only four hours of glufosinate application are about ten times higher compared to that in non-treated leaves. After one day, ammonia levels can be as much as 100 times higher in glufosinate-treated tissues than in non-treated tissues. This higher accumulation of ammonia in glufosinate-treated plants are commonly attributed to the direct inhibition of the glutamine synthetase enzyme by glufosinate. Although previous research reported that ammonia accumulation has been the reason of the plant death, recent research show that ammonia was not the direct driver of the toxic effects of glufosinate.

The series of biochemical events leading to plant death as a result of glufosinate application can be summarized as follows: Glufosinate interrupts many central nitrogen metabolism (nitrogen assimilation) synthetic reactions in plants by inhibiting glutamine and glutamate formation. The absence of both of these important substrates is because of the inhibition of glutamine synthetase. Electron flow in photosynthesis is indirectly inhibited as a result of the decrease in amino donors (from glutamate) for glyoxylate. Glyoxylate accumulates to a level that reduces carbon fixation in the light-independent Calvin cycle, which eventually leads to a complete inhibition of the light reaction in photosynthesis. Under the light conditions, inhibition of electron flow in photosynthesis leads to induction of lipid peroxidation (membrane damage) from an accumulation of triplet chlorophyll. Ammonia accumulation is not linked to the herbicidal effect of glufosinate. The glufosinate mode of action is a good example of how the metabolic pathways of plants are interconnected and how inhibition of an enzyme in one pathway can have a sequential effect in other pathways and lead to plant death. Crop plants tolerant to glufosinate have been developed by genetic engineering technology. The molecular formula of glufosinate is $C_5H_{15}N_2O_4P$ and its chemical structure as shown in (Fig. 3.4).

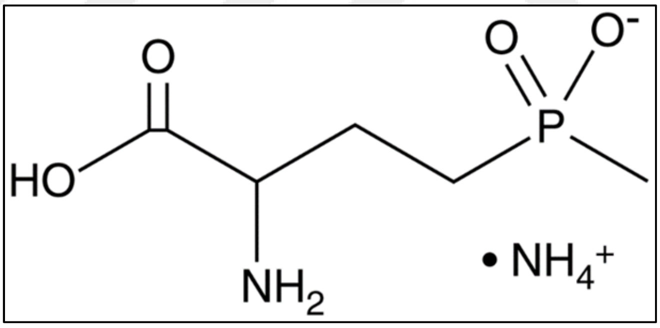

Figure 3.4. Chemical structure of glufosinate ammonium (D-phosphinothricin) salt (Anonymous, 2019c).

Table 3.3. The Target Weeds, Crops and Recommended Doses of herbicide containing Glufosinate Ammonium in Turkey (Anonymous, 2018)

Crops/ Situations	**Weed species**	**Dose (g a.i ha^{-1})**
Grapevines* Citrus	**Annual weeds** Wild mustard (*Sinapis arvensis*) Black grass (*Alopecurus myosuroides*) Sowthistle (*Sonchus spp*.), Wild alfalfa (*Medicago sativa* L.) Hoary plantain (*Plantago media*) Common Lambsquarter (*Chenopodium album* L.) Barnyardgrass (*Echinochloa crus galli*) Crab grass (*Digitaria sanguinalis*) Downy brome (*Bromus tectorum*) Wild lettuce (*Lactuca serriola* L.), Groundsel (*Senecio vulgaris*) Cut-leaved cranesbill (*Geranium dissectum* L.), Common purslane (*Portulaca oleracea* L.) Redroot pigweed (*Amaranthus retroflexus*) Purple nutsedge (*Cyperus rotundus* L.) **Perennial weeds** Johnson grass (*Sorghum halepense* L.) Field bindweed (*Convolvulus arvensis*) Bermuda grass (*Cynodon dactylon*)	600 –1500

*Not to be applied on grapevines its leaves are intended to be eaten. This herbicide is recommended to be applied on weeds at early growth stages.

3.1.2.4. Chemical and Biological Characteristics of 2,4-D Amine

2,4-D [(2,4-dichlorophenoxy) acetic acid] is a white crystalline solid with a vapor pressure of 1.4 × 10–7 mm Hg at 25°C, which can be higher, depending on its chemical form. The acid form of 2,4-D has a water solubility of 900 mg/l (ppm), at 25°C and other molecular forms of 2,4-D differ in their water solubility, for example, butoxyether ester = 100 mg/l (ppm); dimethylamine salt = 796 mg/l (ppm), and the isooctyl ester = 0.0324 mg/l (ppm). The half-life of 2,4-D in the soil is 10 days. The acute oral LD_{50} (rat) for the acid form is 746 mg/kg, and ranges up to > 1000 mg/kg for other formulations. In 1942, Zimmerman and Hitchcock first described the use of 2,4-D as a plant growth regulator (Zimmerman and Hitchcock, 1942). Marth and Mitchell (1944) reported that 2,4-D was effectively controlled dandelion, plantain and other weeds in a bluegrass lawn.

Forms of 2,4-D: commonly include the parent acid, amine salts and esters. These different forms involve the substitution of another chemical group for the terminal hydrogen atom of the acetic side chain of the parent molecule. These substitutions change the physical and biological characteristics of the parent molecule and therefore simplify the use and/or improve the effectiveness of 2,4-D in the field conditions. The comparative efficacy of the various forms of 2,4-D usually refers to their different degrees of phytotoxicity at equal rates of application. The increased effectiveness of a particular form is often related with increased absorption, but the volatility of the compound usually also increases with increased absorption. However, no matter what substitution is available, it is only the parent molecule of 2,4-D that acts as the herbicide at its site of action in the plant. Some forms may contain more than one molecular form of 2,4-D in a certain formulation, for example, two different amines or ester and acid. The concentration of essentially all phenoxy herbicide formulations is expressed as acid equivalent in kilogram per hectare. Acid equivalent refers to that part of the formulation that theoretically can be transformed into the acid. Recommendations are also based on this concept (Monaco et al., 2002).

Acid Forms: acid forms are not commonly used because they are only slightly soluble in water, moderately volatile and relatively high in prices to formulate. Other less expensive forms have the same effectiveness on many weeds. However, acid forms are more effective on certain difficult-to-control weeds than amine forms. They are available as emulsifiable concentrates (EC), alone, or in mixed with other forms of 2,4-D or other herbicides. One formulation contains a 2,4-D ester and is particularly effective against weeds such as field bindweed, russian knapweed, canada thistle, leafy spurge, cattails, tules and nutsedges.

Amines: are produced as a result of reaction between the 2,4-D acid with an amine, creating an amine salt of 2,4-D. There are two main types of 2,4-D amines, namely, water-soluble and oil-soluble amines that are obviously different in their physical and biochemical properties. Water-soluble amines are the most widely used form of 2,4-D in agriculture sector because of their high water solubility, very low volatility, simplicity of handling in the field, and financial costs. They are formulated as water-soluble concentrates. They are relatively less effective than most other forms but provide effective weed control at minimal cost.

Oil-soluble Amines are essentially insoluble in water and are used as emulsifiable concentrates. Their major usefulness is that their effectiveness approaches that of low-volatile esters of 2,4-D with minimal volatility hazards, particularly in hot climate conditions.

Esters: ester forms are produced chemically by reacting the 2,4-D acid with an alcohol, and different types of esters are used. Lengthening of the alcohol side chain leads to a considerable reduction in the volatility of the compound and generally reduces its uptake by plant leaves. Generally, however, esters are translocated within plant tissues more rapidly than any other form of 2,4-D. There are three types of 2,4-D esters: low-volatile esters, high-volatile esters, and invert esters. They are totally different in their physical and biological properties.

Uses: 2,4-D is formulated as an EC, SL, SP, SL, and G; and sold under a wide range of trade names and used primarily as a post-emergence treatment to control annual and perennial herbaceous and woody weeds. It has been registered and recommended for use in corn, small grains, grain sorghum, rice, sugarcane, orchards, cranberries, strawberries, asparagus, turf, pastures and rangeland, conifer release, aquatic situations, and non-cropped situations worldwide. 2,4-D also has some herbicidal activities in the soil and is used as a pre-emergence herbicide in corn post-planting, but before crop emergence on soils with a high organic matter. Phytotoxicity to the corn can happen if the herbicide is soil applied on rough-textured and low organic matter soils. It is used in soybeans as an early pre-plant soil application at least 30 days after of no-till planting (Monaco et al., 2002).

Mode of Action: On broadleaf weeds, epinasty is the most obvious effects of all growth regulator herbicides. Plants treated with 2,4-D are usually develop grotesque and malformed leaves and stems. Brace roots of corn also grow abnormally. The herbicides concentrate in young embryonic or meristematic tissues that are growing rapidly, and these tissues are more sensitive than mature or relatively inactive young tissues. Histological studies on red kidney beans indicated that the cambium, endodermis, embryonic pericycle, phloem parenchyma, and phloem rays were significantly changed by 2,4-D. The cortex and xylem parenchyma showed a slight response, and the epidermis, pith, mature xylem, mature sieve tubes, and differentiated pericycle showed no response to 2,4-D application. These findings suggest that active cell division is necessary for the development of 2,4-D injury symptoms. The types of tissues affected by 2,4-D in field bindweed and sow thistle were relatively the same as those affected in beans. Leaves rapidly absorb non-polar forms (acids, esters, oil-soluble amines) of 2,4-D, while polar forms (inorganic salts, water-soluble amines) are more slowly absorbed. The use of surfactants generally increases foliar uptake, and absorption increases with increasing temperature and humidity. Plant stems and roots also more likely to absorb all these forms. Rainfall shortly after application may reduce efficacy, but rainfall 6 to 12 hours after treatment has a little effect. Non-polar forms of 2,4-D have a tendency to resist rain wash off. After absorption by plant foliage, all these herbicides are translocated throughout the plant in the phloem. With 2,4-D, it was shown to move from the leaves (source) with the photosynthate in the phloem, but more slowly than the photosynthate itself. 2,4-D is usually accumulates in the sink areas of the plant (e.g., developing organs and meristems). Limited translocation occurred in grasses compared to broadleaves, which may slightly explain grass tolerance to 2,4-D (Ashton, 1958). Movement of a foliar-applied herbicide to underground parts such as roots and rhizomes is of a paramount importance for the control of perennial weeds. Therefore, periods of maximum growth and photosynthate accumulation in those underground organs and minimum growth of the shoot parts significantly support the control of perennial weeds. This generally occurs in the fall for most perennial weeds but may occur at other times of the year for certain perennial weed species. The extreme dose of 2,4-D may injure the phloem and reduce translocation process; therefore, successive low application rates usually give effective control of perennial weeds than a single high application rate. Plant age and associated rate of growth greatly affect susceptibility; however, this will vary with different growth regulator herbicides. Generally for 2,4-D, younger plants are more susceptible than mature plants of the same species. However, some plants are tolerant while small, and others never gain more than slight tolerance throughout their lifetime. Some plants may develop a second period of susceptibility at certain growth stage. For example, small grains are very susceptible to 2,4-D in the germination and small dicotyledonous stages but become tolerant later in the tillering stage, susceptible again in the jointing, heading and flowering stages, and tolerant again in the soft-dough stage. The periods of susceptibility synchronize with periods of rapid growth. At this time, the cells of the meristems are dividing readily, have a high level of metabolic activity, and are very susceptible to 2,4-D. The biochemical and metabolic changes in plants suggested to be persuaded by growth regulator herbicides are numerous. Studies suggest that nucleic acid metabolism and the metabolic aspects of cell wall plasticity are most relevant to the mechanism of action of growth regulator herbicides. Early studies indicated that stimulated synthesis of RNA and DNA in indole acetic acid-treated tobacco pith cells. A few years after the introduction of the phenoxy herbicides, similar results were reported in a wide range of plant tissues exposed to these herbicides. 2,4-D seems to be acting in a way similar to the native auxin (IAA). However, IAA has endogenous control mechanisms that maintain its concentration within the appropriate physiological range. Growth regulator herbicides have no such control mechanisms. It is well known that 2,4-D can stimulate or inhibit cell growth, depending on the concentration reaches the tissue. The 2,4-D is a systemic, selective, post-emergence herbicide most commonly used for control of broad-leaf weeds in cereal crops such as corn sorghum, maize, etc (table 3.4).

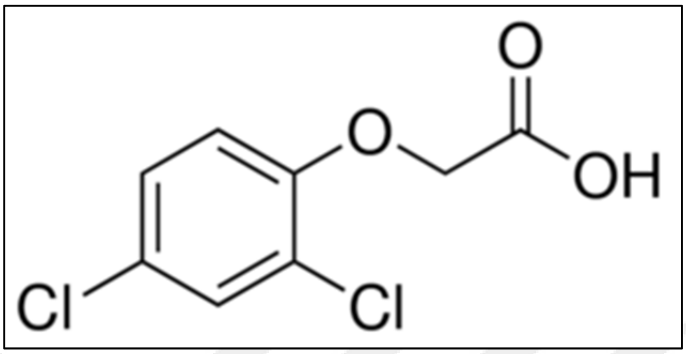

Figure 3.5. Chemical structure of 2,4-dichlorophenoxyaceticacid active ingredient (Anonymous, 2019a).

Table 3.4. TheTarget Weed Species, Crops and Recommended Doses of herbicide containing 2,4-D Amine in Turkey (Anonymous, 2018)

Crops/ Situations	**Weed species**	**Dose (g a.i. ha^{-1})**
Cereals	Pheansant's eye (*Adonis flamea* Jacq.) Corncockle (*Agrostemma githago* L.) Cerastium (*Cerastium perfoliatum* L.) Creepingbellflower (*Campanula rapunculoides*) Syrian cephalaria [*Cephalaria syriaca* (L.) Common chicory (*Cichorium intybus* L.) Field larkspur (*Consolida anthorodea* Boiss) Anatolian pink (*Dianthus anatolicus* Boiss.) Fumaria (*Fumaria kraliki* Jord.) Henbit dead-nettle (*Lamium amplexicaule* L.) Yellow pea (*Lathyrus aphaca* L.) Field gromwell [*Buglossoides arvensis* (L.) Yellow sweat clover [*Melilotus officinalis* (L.)] Common poppy (*Papaver rhoeas* L.) Prostrate knotgrass (*Polygonum aviculare* L.) Corn buttercup (*Ranunculus arvensis* L.) Wild radish (*Raphanus raphanistrum*) Wild mignonette (*Reseda lutea* L.) Wild mustard (*Sinapis arvensis* L.) Hedge mustard [*Sisymbrium officinale* (L.) Chickweed [*Stellaria media* (L.) Vill.]	800-1000-1500

	Meadow salsify [*Tragopogon bupthelmo*] Broadleaf false carrot (*Turgenia latifolia* L.) Vaccaria [*Vaccaria pyramidata* (Medik.)] Germander speedwell (*Veronica chamaedrys* L.) Corn charmomile (*Anthemis arvensis* L.)	
Corn	Redroot pigweed (*Amaranthus retroflexus*) Common Lambsquarter (*Chenopodium album*) European heliotrope (*Heliotropium europaeum*) Wild radish (*Raphanus raphanistrum*) Wild mustard (*Sinapis arvensis* L.)	1000

3.1.2.5. Chemical and Biological Characteristics of Picloram

Formulation: SL (soluble liquid concentrate)

Molecular formula: $C_6H_3Cl_3N_2O_2$

Chemical structure: as shown in (Fig. 3.5).

Picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) is a white powder with a vapor pressure of 6.16 × 10–7 mm Hg at 35°C, a water solubility for the acid of 430 mg/l (ppm) and 200,000 mg/l (ppm) for the amine salt at 25°C, a soil half-life of 90 days and an oral LD_{50} (rat) of >5000 mg/kg for the acid and the amine (Monaco et al. 2002). Picloram is a restricted-use pesticide that is highly active and very mobile, yet very persistent, in the soil, often persisting into the next growing season. Very small amounts can effectively control or injure many broadleaf weeds. Extreme care must be taken when applying picloram to prevent its drift to the non-target site.

Uses: Picloram is commonly found in a soluble liquid concentrate formulation which effectively control a wide range of perennial broadleaf weeds and shrubs in non-cropland, roadsides, natural areas, grass pastures, and in small grain fields. Picloram is also sold in combination with many 2,4-D forms to be used in permanent grasslands and rangeland. It is both foliage and soil-applied herbicide and is also used as a basal or cut surface treatment for unwanted tree control, particularly against mesquite plants.

Soil Influences: Organic matter and certain clays adsorb considerable amount of picloram. Picloram is readily leached through sandy and montmorillonite clay soils low in organic matter, but not through lateritic soils or soils with high organic matter. Salts of picloram seems to be leached more readily than the parent acid form. Picloram is very persistent in soils, which is one of the reasons it is considered a restricted-use herbicide. Microorganisms slowly degrade it in the soil. Conditions that favour microbial growth, such as warm, moist soil and organic matter, reduce its period of persistence. The application rate also influences its period of phytotoxicity in soils. Phytotoxicity may often be detected well over one year after application.

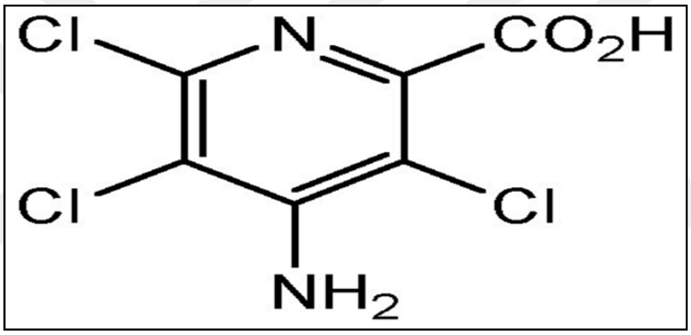

Figure 3.6. The chemical structure of the picloram.

3.1.2.6. Chemical and biological Characteristics of Triisopropylamine

The triisopropylamine is a basic chemical used for a variety of industrial applications including as an emulsifier, stabilizer, intermediate and agricultural product. Triisopropylamine is an aminoalcohol belongs to the chemical group of alkanolamines. It’s white to yellow, solid at room temperature. It is a completely soluble in water and has a slight ammonia-like odor. The triisoropylamine neutralizes acidic herbicides and other acidic compounds.

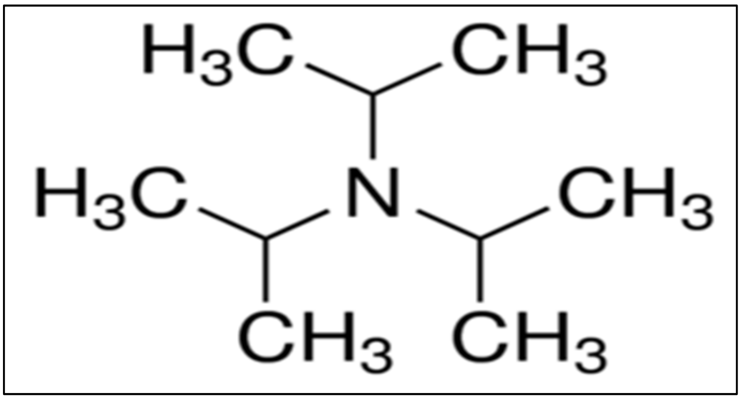

Figure 3.7. The chemical structure of triisopropylamine.

The premix herbicide (triisopropylamine+picloram) is commonly used against woody plants in green areas, non-cropped areas, airports and historic places.

Weeds affected: As shown in Table (3.5).

Table 3.5. The Target Weeds, Crops and Recommended Doses of 2,4-D Tri-isopropylamine+Picloram in Turkey (Anonymous, 2018)

Crops/ Situations	Weed Species	Dose (g a.i. ha^{-1})
Green areas	Common dandelion (*Taraxacum spp.*) Broadleaf plantain (*Plantango spp.*) Clover (*Trifolium spp.*)	567.7
Non-cropp areas, airports, historic places	Common couch (*Agropyron repens*) White clover (*Trifolium repens*) Soft brome (*Bromus hordeaceus*) Field horsetail (*Equisetum arvense*) Field eryngo (*Eryngium campestre*) Blackberry (*Rubus* spp.) Crab grass (*Digitaria sanguinalis*) Dwarf mesquite (*Prosopis farcta*) Shepherds purse (*Capsella bursa-pastoris*) Puncturevine (*Tribulus terrestris*) Common cocklebur (*Xanthium strumarium*) Stork's bill (*Erodium cicutarium*) Wall barley (*Hordeum murinum*) Corn buttercup (*Ranunculus arvensis*) Rough bindweed (*Smilax aspera*) Yellow star-thistle (*Centaurea solstitialis*)	3973.9 - 5677

	Common fumitory (*Fumaria officinalis*) Dyer's alkanet (*Alkanna tinctoria*) Chaste tree (*Vitex agnuscastus*) Amaranth (*Amaranthus* spp.) Salt cedar (*Tamarix* spp.) Groundsel (*Senecio vulgaris*) Common horehound (*Marrubium* spp.) Berberis (*Berberis crataegina*) Common reed (*Phragmites communis*) Summer pheasant's eye (*Adonis* spp.) Johnson grass (*Sorghum halepense*) Field elm (*Ulmus campestris*) Garland thorn (*Paliurus spina-christi*) French lavender (*Lavandula stoechas*) Bean clover (*Anagyris foetida*) Hooked bristlegrass (*Setaria verticillata*) Tree of heaven (*Ailanthus altissima*) Bermuda grass (*Cynodon dactylon*) Black nightshade (*Solanum nigrum*) Creeping thistle (*Cirsium arvense*) Dock (*Rumex* spp.) Oak (*Quercus* spp.) Gancao (*Glycrrhiza* spp.) Spiny restharrow (*Ononis spinosa*) Broadleaf false carrot (*Turgenia latifolia*) Field marigold (*Calendula arvense*) Downy brome (*Bromus tectorum*) Wild jasmine (*Jasminum fructicans*) Willows (*Salix* spp.) Spurge (*Euphorbia* spp.) Field bindweed (*Convolvulus arvensis*) Annual bluegrass (Poa annua) Black grass (*Alopecurus myosuroides*) Stone fruits (*Prunus* spp.) Vetches (*Vicia* spp.) Wild rose (*Rosa* spp.) Wild mustard (*Sinais arvensis*) Wild carrot (*Daucus carota*) Hoary cress (*Cardaria draba*) Alfalfa (*Medicago* spp. = *Medicago sativa*) Wild oat (*Avena fatua*) Wild olive (*Olea sylvestris*) Goatsbeard (*Tragopogon latifolius*) Green foxtail (*Setaria viridis*) Cleavers (*Galium* spp.)	

3.1.3. The Equipment used in Laboratory Experiments

The main materials used in the germination and dormancy breaking experiments, which conducted in the laboratory, were the mesquite seeds, constant-temperature incubators, glass Petri dishes, filter papers, distilled water, etc. More details on these materials were given below:

3.1.3.1. The Constant Temperature Incubators

Different types of constant-temperature incubators were used for seed germination. However, the nuve model has been the most frequently used incubator. The volume of the incubator was approximately 50 litres, with temperature range of 5°C to 70°C, ±0.5°C accuracy and ±0.5°C stability. The main controller was equipped with a timer and automatic digital PID controller. The inside dimensions of incubator were 400x300x400mm, and outer dimensions of 580 x 530 x 600 mm (Fig. 3.8).

Figure 3.8. Constant-temperature incubators (nüve ES 500) used for mesquite seed germination.

3.1.4.2. Mesquite seeds Used in the Laboratory and Greenhouse Experiments

Seeds of dwarf mesquite (*Prosopis farcta*) were used in germination biology, dormancy breaking and greenhouse experiments. Dwarf mesquite seeds are dark brown in colour, obovate to broadly elliptic in outline, 6.3 – 8.5 mm long, 4.5 – 6 mm wide, 1.7 – 3 mm thick, without an umbo and sometimes depressed centrally, narrowly elliptical in cross section. The seed has a pleurogram with relatively short arms, broadly open, distinctly wide in some cases, and close to seed margins. Lens recessed, diamond shaped. Pods of *P. juliflora* were brought from Sudan in 2016 and dissected in the laboratory using a plier. The pods are 10 – 23 cm long, 1 – 2 cm wide, cylindrical or slightly irregularly curved, start green and turns to yellow when ripening, contains 20 – 32 hard oval or elliptic yellow seeds (2.5 – 7 mm long). Seeds are very difficult to be scraped out from pods (Fig. 3.8).

Figure 3.9. Seeds of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.] and common mesquite [*Prosopis juliflora* (Sw.) DC.] used in all experiments.

3.1.4. Equipment Used in the Greehouse Experiments

There are many materials and tools have been used through the different stages of the greenhouse experiments. The major equipment in the greenhouse were the plastic pots, a mixture of soil and organic matter, mesquite seeds, a rechargeable knapsack sprayer, herbicides, a sensitive scale, and so on.

General Information about the Greenhouse: The greenhouse used in our study was a conventional vertical-sided greenhouse located in the Experimental Research Farm of the Department of Plant Protection (37 01'47.95"N 35 21'40.97"E). This greenhouse was built in an area of 6 x 14 m (84 square metres). The greenhouse body was made from glass with the wall was painted with a lime-based whitewash as a shade cover to reflect more sunlight and heat back to the atmosphere and minimize the heat during the summer months. The roof is sloped towards a central ridge and the door is in one of the two peaked ends. The greenhouse has a sidewall about 5 feets high and a central ridge stands about 5-10 feet above the floor. An eco-friendly green net made up of polyethylene was hanged on the top side of the greenhouse at a height of about 3 meters as a shade cloth to reduce the light level, minimize water evaporation and keep the greenhouse cool. The greenhouse was also equipped with a hot-water heating system to be used in the winter months (Fig.3.10).

Figure Figure 3.10. A conventional greenhouse used to conduct a chemical control experiment for two mesquite species [*Prosopis farcta* (Banks & Sol.) J.F. Mac. and *Prosopis juliflora* (Sw.) DC.].

3.1.4.1. The Plastic Pots Used in the Greenhouse

Plastic pots used in greenhouse experiments were cylindrical, 15 cm height x 17 cm top diameter x 13 cm bottom diameter. The pot volume was approximately 2 litres. In all experiments, pots were filled with soil mixture to within approximately 3 cm of the top.

3.1.4.2. The Soil Used in the Greenhouse

The soil used in these experiments was a mixture of 40% sand, 40% silt and 20% animal manure. Soil was prepared at least two days before seed sowing.

3.1.4.3. Mesquite Seeds Used in the Greenhouse Experiment

Seeds of the two mesquite species were used in the two-year greenhouse experiments. More information about the seeds were provided above (Fig. 3.8).

3.1.4.4. Knapsack Sprayer

A rechargeable electric knapsack sprayer of E^+ Matabi, with a total capacity of 15 litres was used for herbicide application in greenhouse experiment. The sprayer has an electric pump suitable to spray any pesticide including wettable powders (WP). It's equipped with a battery charger, conical hood, set of tee-jet nozzles, and pressure regulator integrated into the handle, which could be adjusted to work between 3 to 1.5 bars. The sprayer also has a continued mixing function (Fig. 3.11).

Figure 3.11. A rechargeable electric battery sprayer (Matabi) used for herbicide application in the greenhouse experiments.

3.1.5. Equipment and Tools Used in the Field Experiments

In the field experiment, meaturing tape, wooden stakes, plastic plant tags were utilized to layout the experiment design. Five different herbicides, a motorized sprayer and personal protective equipment (PPE) were used during herbicide application. In addition, a sensitive scale and drying oven were used to calculate the plant biomass. These equipmet are briefly explained in the section below.

General Information about the Study Area: The study was set on a non-crop field in the Experimental Research Farm of Çukurova Unversity (37 01′45.93″ N 35 21′42.41″ E) situated in Adana province. This area was selected because of its high dwarf mesquite infestation level. Adana province is located in the Çukurova Delta in the central part of the Mediterranean Region of Turkey and characterized by its Mediterranean climate, which is generally warm and dry in summers and cool and rainy in winter months. The long-term meteorological data show that the average annual precipitation in Adana is 654.4 mm (Anonymous, 2019b). The soils of Çukurova Delta are generally classified as solonshak-like soils with a high content of soluble salts (Dinç, 1974). The reclamation of the saline soils following the irrigation drainage activities in Adana was studied by Landsat for a period of 30 years (Dinç et al., 1991). As a result, the reclaimed soils of the region were grouped into three classes: (i) almost totally reclaimed soils found in the associations of bajadas, river terraces, and bottom lands; (ii) partially reclaimed soils located at the lower end (the southernmost area) of the region comprising saline marshy soils of the tidal marshes and soils with increased salinity and/or salinity alkalinity of the Sand dune associations and the Saline Marshy Soils in the southeast most tip of the region. In an updating monitoring study conducted in the same area it was determined that the salinity of the upper northern part of the Çukurova Delta that developed during the above-mentioned periods was almost completely reclaimed, whereas the soils of the middle parts of the Çukurova Delta revealed partial reclamation following the completion of the drainage infrastructure. The far south part faced an increased salinity around the lagoonal lakes (lowest parts of the delta) which were spread to wider areas in the last decade, due to the accumulation of the drainage waters derived from the upper delta (Şatır et al., 2010).

3.1.5.1. Measuring Tape Used for Measuring the Study Units

A flexible, 50 m long x 2 cm wide, open reel measuring tape, made of fiberglass, was used to measure the study units (blocks, parcels, interblocks spaces). The unit size was determined according to the spray width delivered by the herbicide sprayer.

3.1.5.2. Wooden Stakes Used to Divide the Study Area

Throughout the field experiments, dry and strong stems of giant reed (*Arundo donax* L.), a common aquatic weed in Çukurova region, were cut and used as wooden stake. A total of 152 stakes, 50 cm each, was used for each experiment. All stakes were tapered to a thin edge and one stake was fixed at each corner of a block after all the field units being measured. This plant was utilized as a source of wooden stakes because of the impermanence of its stems which break down quickly and does not limit the farmers' movement within the farm.

3.1.5.3. Plant Labels Used for Plant Marking

Yellow plastic plant labels (plant tags) were utilized in marking specific plants in each block to help recording the targeted study parameters. The yellow color of the tags was chosen to be more visible while monitoring and collecting data. Despite being environmentally undesirable, the plastic material was proved to be more persistent and suitable for field studies when handled appropriately.

3.1.5.4. Motorized Knapsack Sprayer

The sprayer used was 350 x 220 x 350 mm in dimensions, weighing 9 kg, with a tank capacity of 25 litre. The chemical liquid tank is strong, easy to clean, made up of polyethylene, with UV inhibitors for long life. The liquid tank is marked and each mark indicates the 5, 10, 15, 20 and 25 litre levels. On the top there is a cap equipped with a filing strainer. This instrument is operating by an engine fuelled by a mixture of gasoline and two-cycle engine oil added in a ratio of 50:1. Gasoline or gasohol is known to be good. Gasoline should contain a maximum of 10% ethyl alcohol or 15% methyl tertiary-butyl ether (MTBE) is allowed for this engine. The sprayer equipped with a discharge volume pump connected to a 2.5-meter-long handheld boom equipped with five TeeJet nozzles. Five nozzles were placed in 25 cm distant from each other and adapted to spray full width of one plot (2.5 m). The sprayer was also equipped with shoulder straps adjustable to fit any operator (Fig. 3.12).

Figure 3.12. A motorized backpack sprayer used for herbicide application on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] during the field experiments.

3.1.5.5. The Sensitive Scale

A Sartorius Werke GMBH laboratory balane (of the German Membrane Filter Company, 1978) was used for measuring the fresh and dry weights of plants harvested at the end of the experiments. The scale is constructed of aluminium frame and stainless steel weighing pan. On the front side there was a screen shows the measurements. The device equipped with a bottoms help adjusting the milligram unit. The maximum weighing capacity of the instrument was 1600 g, with good accuracy and fairness (Fig. 3.13).

Figure 3.13. A sensitive scale used for measuring the fresh and dry weights of plant harvested from both greenhouse and field studies.

3.1.5.6. The Drying Oven

Thermo Heraeus T12 drying oven was used to dry plant shoots harvested (Fig. 3.14). The interior volume of the oven was 110 litre with external dimension of 696/850/540mm and interior dimensions of 496/575/386 mm. The instrument has a total of 15 shelve spaces, with shelf dimensions of 480/365 mm. The operating temperature ranging from +10 °C to 250 °C and temperature deviations reach ±5 °C after 150 °C. The device consumes 1.82 Kw of power and transfers 700W of heat to the environment (Anonymous, 2007).

Figure 3.14. Drying oven used for drying plant shoots.

3.2. Methods

3.2.1. Germination Biology Experiments of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] and Common Mesquite [*Prosopis juliflora* (Sw.) DC.]

In these experiments seeds of dwarf mesquite (*P. farcta*) and common mesquite (*P. juliflora*) were obtained and their germinatability was evaluated under a range of temperature degrees.

3.2.1.1. Mesquite Seeds Collection

Mature pods of dwarf mesquite (*P. farcta*), were collected in June 2017, from plants of the previous growing season in three different locations [Çatalan (37 11′56.23″ N 35 17′48.00″ E), Karaömerli (37 07′04.21″ N 35 20′39.88″ E) and Çirişgediği (37 08′46.81″ N 35 23′16.68″ E)] in Adana province, Turkey. These pods were then dissected and healthy seeds were stored dry in paper bags for five months at room temperature in the laboratory until used in the experiment.

However, pods of common mesquite (*P. juliflora*) were collected from a marginal site in Khartoum, Sudan in February, 2016 and brought to the Weed Science laboratory of Çukurova University, Turkey. Afterwards, pods were dissected and seeds were stored dry in the laboratory before being tested for germination.

3.2.1.2. Design of the Germination Experiments

All experiments were conducted in the Weed Research Laboratory of Çukurova University, Adana, Turkey. Germination responses to temperature were tested for dwarf mesquite and common mesquite seeds incubated at nine constant temperatures from 5°C to 45°C, at 5°C intervals. For each treatment, four replicates of 25 seeds of common and dwarf mesquite were independently placed in 9-cm-diameter sterilized glass Petri dishes containing double layer of filter paper moistened slightly with distilled water (Fig. 3.15). Throughout the experiment, seeds were kept moist after being placed in incubators with constant temperatures of 5, 10, 15, 20, 25, 30, 35, 40, and 45 C° degrees in the dark. On the 1st, 3rd, 5th, 7th, 14th, 21st, and 28th days of the experiment, seeds were monitored for germination and the number of germinated seeds were counted, recorded and removed (Uygur, 1985). Seed germination was defined as when a radicle protruded at least 5mm out of the seed coat. At the end of the experiment the final germination percentage in each temperature was calculated and the minimum, maximum and optimum temperatures were determined. The entire experiment was repeated twice in the first year (2016) and twice in the second year (2017) in winter.

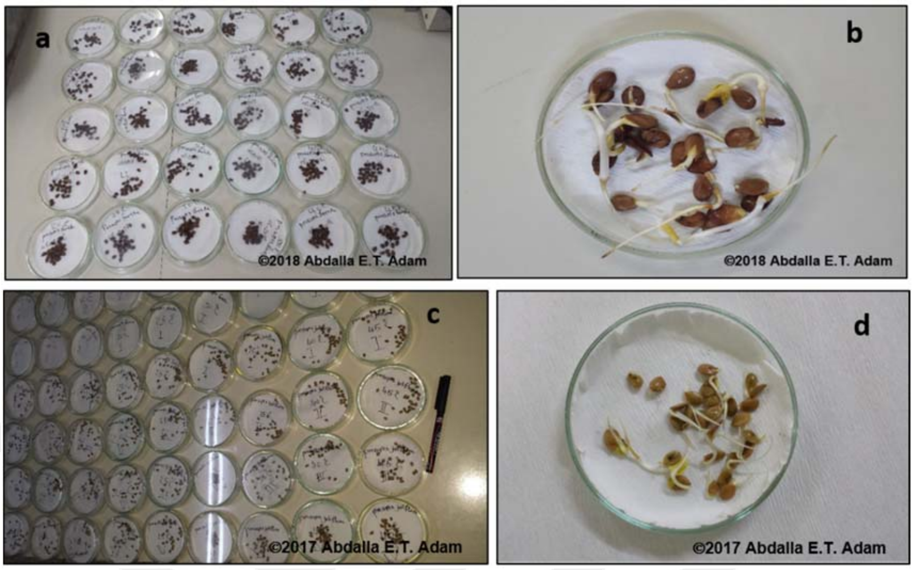

Figure 3.15. Experiment design and germinated seeds of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] (a, b), and common mesquite [*Prosopis juliflora* (Sw.) DC.] (c, d).

3.2.2. Seed Dormancy Breaking in Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] and Common Mesquite [*Prosopis juliflora* (Sw.) DC.]

In these experiments, different methods (pre-chilling, pre-heating and seed cutting) were tested for their ability to break the physical dormancy in the mesquite seeds. For each treatment, four replicates of 25 seeds were tested for germination. Four treatments consisting of 24 hour pre-chilling at (-5 C°), 24 hour pre-chilling at (+5 C°), 24 hour pre-heating at (40 C°) and mechanical scarification of seed coat were applied independently on each species. Seeds were therefore divided into five batches, four Petri dishes each and subjected to these five treatments. The mechanical scarification was achieved by cutting the edge of each seed carefully on the opposite side of the cotyledon without injuring the embryo to avoid causing any adverse effects on seed viability. After being exposed to these treatments, seeds were transferred to two independent germination incubators adjusted at the optimum germination temperature (30 C° for dwarf mesquite seed and 35 C° for common mesquite seeds), which determined previously during the germination biology studies. The number of germinated seeds was counted at 1, 3, 5, 7, 14, 21, and 28 days after placement and germinated seeds were removed. However, to prevent potential common mesquite plant invasion in the region, all seeds, including germinated one, were completely burnt after experiments using a controlled wood-burning stove.

3.2.3. Chemical Control of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] and Common Mesquite [*Prosopis juliflora* (Sw.) DC.] under Greenhouse Conditions

Greenhouse experiments were conducted in May during the two consecutive dry seasons of 2017-2018 and 2018-2019; at the Department of Plant Protection of Çukurova University (37 01'47.95"N 35 21'40.97"E) to assess the herbicidal activity of five different herbicides on the two mesquite species. Therefore, seeds were sown about one cm deep in 15 cm height x 17 cm top diameter x 13 cm bottom diameter plastic pots filled with a fine-textured soil made up of 2:2:1 of sand, silt and animal manure, respectively. Five seeds were sown in each pot and thinned into one seedling per pot when reached the first true leaf development stage. The developmental stages of plants were determined according to the coding system BBCH. Consequently, when the plant seedlings reached BBCH stage 31, the pots were arranged in a completely randomized of split-plot design with six replicates and five herbicides, namely; 2,4-D amine, glyphosate diammonium, glyphosate potassium, glufosinate ammonium and 2,4-D triisopropylamine+picloram (4-amino-3,5,6-trichloro-picolinic acid) were applied early in the morning of a relatively windless day. Throughout the experiments, the pots were kept in greenhouse with an average temperature of 25/20 ±2C° day/night and 65% relative air humidity. All herbicides were applied in three doses; (i) recommended dose = N, (ii) two-third dose = 2/3 N and (iii) half dose = ½ N (Table 3.6).

Table 3.6. Herbicides and Rates Applied on Common Mesquite [*Prosopis juliflora* (Sw.) DC.] and dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] in the greenhouse and field experiments

Herbicides	**½ N (g a.i ha^{-1})**	**2/3 N (g a.i ha^{-1})**	**N (g a.i ha^{-1})**
Glyphosate diammonıum salt	1696	2261	3392
Glyphosate potassium salt	1984	2646	3969
Glufosinate ammonium salt	750	1000	1500
2,4-D Amin salt	750	1000	1500
2,4-D triisopropylamine+Picloram	2838	3784	5677

Spray volume of 300 l/ ha was applied using a rechargeable knapsack sprayer (Matabi) equipped with a handheld boom and TeeJet nozzles adjusted to air pressure of 3 bars to reduce off-target herbicide movements. Visual observations on the individual plant level were then performed on 1, 3, 5, 7, 14, 21, 28 and 56 days after treatment (DAT) and percentage of weed control (% control) and plant height (cm) were recorded. The stems were eventually cut off just above the soil surface and the fresh weight was recorded. Consequently, plants were placed in paper bags and dried in a laboratory oven at 105 °C for 24 h and the dry weights were determined. Eventually, the biological effect on dwarf mesquite biomass was expressed as a percentage reduction in fresh weight (FW) and dry weight (DW) compared to the untreated control checks (Fig. 3.16).

Figure 3.16. Greenhouse experiment for chemical control of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] (a,b) and common mesquite [*Prosopis juliflora* (Sw.) DC.] (c,d).

3.2.4. Chemical Control of Dwarf Mesquite [*Prosopos farcta* (Banks & Sol.) F.J. Mac.] under Field Conditions

Adana Province is located in the central part of the Mediterranean Region of Turkey. The province has a Mediterranean climate, with warm, dry summers and cool, rainy winters. According to long-term meteorological data, the average annual precipitation in Adana is 654.4 mm (Anonymous, 2019b). The area was chosen because of its high levels of dwarf mesquite infestations, despite the use of herbicides. Additionally, weed species present on each plot area were identified and their average densities were determined using one-metre square quadrant (Table 3.7).

Table 3.7. Names of weed species and their densities within the study area

Weed species	**Weed density ($plants/m^2$)**
Cocklebur (*Xanthium strumarium* L.)	30 ± 5
Common purslane (*Portulaca oleracea* L.)	35 ± 3
Dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.]	8 ± 4
Dyer's cotton (*Chrozophora tinctoria* Rafin.)	5 ± 1
Field bindweed (*Convolvulus arvensis* L.)	45 ± 5
Johnson grass [*Sorghum halepense* (L.) Pers.]	10 ± 3
Jute (*Corchorus olitorius* L.)	2 ± 1
Knotweed (*Polygonum cognatum* Meissn.)	13 ± 2
Pigweed (*Chenopodium album* L.)	27 ± 6
Purple nutsedge (*Cyperus rotundus* L.)	22 ± 4
Red-root amaranth (*Amaranthus retroflexus* L.)	11 ± 2
Spurge (*Euphorbia* spp.)	50 ± 5
Venice mallow (*Hibiscus trionum* L.)	12± 2

The Design of Field Experiment: In July 2017, a field experiment was conducted in a non-crop site at the Experimental Research Farm of Çukurova University (37 01′45.93″ N 35 21′42.41″ E) to evaluate the efficacy of five different herbicides (glyphosate diammonium salt, glyphosate potassium salt, glufosinate ammonium salt, 2,4-D amine and 2,4-D + picloram) on dwarf mesquite. The experiment was laid out in a randomized complete block design with an individual plot size of 17.5 m^2 with four replications (Fig. 3.18).

Figure 3.17. The field experiment for chemical control of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] in the Experimental Research Farm of Çukurova University

The treatments consisted of five herbicides (three doses each), a weed-free and a weedy check. The three doses of herbicides applied in this experiment were (i) label recommended dose = N, (ii) two-third dose = 2/3 N and (iii) half dose = ½ N (Fig. 3.19).

I	A RS	B RS	C RS	A TD	B TD	C TD	A TR	B TR	C TR	A 2,4-D	B 2,4-D	C 2,4-D	A GN	B GN	C GN	WD	WF
0.5 m																	
II	A GN	C TR	A 2,4-D	C TD	WD	B GN	C RS	A TD	WF	B 2,4-D	C GN	A TR	C 2,4-D	A RS	B TR	B TD	B RS
0.5 m																	
III	C TR	B 2,4-D	A TD	B RS	WF	A 2,4-D	B TR	C RS	A GN	B TD	A RS	B GN	C TD	A TR	C 2,4-D	WD	C GN
0.5 m																	
VI	B RS	C RS	A TD	A GN	C 2,4-D	WD	WF	C TR	A 2,4-D	C GN	B TD	B 2,4-D	A RS	B TR	C TD	B GN	A TR

Figure 3.18. Experimantal design for chemical control of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F Mac.] and common mesquite [*Prosopis juliflora* (Sw.) DC.] under the field conditions.

RS: glyphosate potassium*TD: glyphosate diammonium*
TR: 2,4-D tri-isopropylamine + picloram
2,4-D: 2,4-D amine
GN: glufosinate ammonium
WD: Weedy check
WF: Weed-free check
A: the half dose
B: the 2/3 N two-third dose
C: the recommended dose

Herbicide application was done on mesquite at BBCH 33 phenological growth stage, in a spray volume of 300L/ha using a motorized backpack sprayer and TeeJet nozzle adjusted at a discharge pressure of 3 bars to minimize wind drift. The spraying height was about 45 cm above the plant and each parcel (17.5 m^2) was sprayed with 525 ml of solution. Visual estimates of phytotoxic effects on dwarf mesquite were recorded at 1, 3, 5, 7, 14, 21, 28, and 56 DAT and expressed as percent weed control. Plant height was also recorded. At the end of the experiment, plants were harvested and fresh and dry weights of shoot were measured.

Figure 3.19. Chemical control of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] using five different herbicides under field condition (a = experiment design; b = weed-free untreated check; c = weedy check; d = 2,4-D; e = glufosinate ammonium; f = 2,4-D + picloram; g = glyphosate diammonium; h = glyphosate potassium; i = sample harvest).

3.2.5. Growth and Phenology Experiments for Dwarf Mesquite [*Prosopos farcta* (Banks & Sol.) F.J. Mac.]

Experiments were carried out in a non-crop field situated in the central part of Çukurova basin which represents the eastern Mediterranean region of Turkey. The design of the growth phenology experiment: To investigate the phenological characteristics and reproductive capacity of dwarf mesquite, a field experiment was performed for two seasons (2017/2018 and 2018/2019) at the Experimental Research Farm of Department of Plant Protection, Çukurova University (37 01′45.93″ N 35 21′42.41″ E). Since dwarf mesquite is a continuous perennial shrub, the foliage is naturally dies back to the ground in winter, then sprout from the crown in spring. Therefore, in February, experiments were carried out in a non-cropped area where 100 representative, pest-free dwarf mesquite plants of the previous season were selected randomly from ten sites (10 plants each) then marked and numbered using colored plastic plant labels. Plants were then daily monitored and developmental stages such as flowering, fruit ripening, and seed-casting dates were determined in accordance with the BBCH scale (Finn et al., 2007), and photographed. Eventually, the annual seed production per plant was studied.

3.2.6. Investigating the Effect of Herbivorous Insects on Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.]

The study was carried out in Adana Province, situated on the Seyhan River near to the Mediterranean Sea. The climate in Adana is generally characterized by its warm, dry summers and cool, rainy winters. The long-term meteorological data show that the average annual precipitation in Adana is 654.4 mm (Anonymous, 2019b). The study area was invaded by the dwarf mesquite, with other herbaceous weed species. The common characteristics of the mode of production in this area is grain and horticulture, where maize, corn and citrus farming is practiced. Three representative fields in three villages were selected to determine the impact of herbivorous insects on the seed pods of dwarf mesquite.

3.2.6.1. Sample Collection

Sample collection was conducted in three different locations of a climatically similar area in Adana Province [Çatalan (37 11′56.23″ N 35 17′48.00″ E), Karaömerli (37 07′04.21″ N 35 20′39.88″ E) and Çirişgediği (37 08′46.81″ N 35 23′16.68″ E)] with dwarf mesquite-infested fields. In April 2016, fully mature pods were picked by hand from *P. farcta* plants. Because of difficulties in separating irrigated fields from non-irrigated fields, the irrigation factor was not considered an independent variable. Sampling events were conducted in both irrigated and non-irrigated fields. Collections were made from a field of about 0.4-0.5 ha at each of the three sites. Since the plant was more abundant in the field margins than in the field centers, samples were mostly collected from the field margins throughout the sampling period. Ten to twenty plants were sampled in each field and a total of 501 pods were collected randomly from the three sites. Samples were placed in paper bags, brought to the laboratory and carefully enveloped with a plastic material to prevent the insects from escaping until dissection.

3.2.6.2. Dwarf Mesquite Pod Dissection and Examination

The pods from each location were categorized into two batches: (1) pods showing insect entrance/exit holes - ‘Infested pods’, and (2), pods without any visible holes - ‘Healthy pods’. The number of holes per pod was then recorded. Pod diameters were measured with calipers and the following characters were recorded: pod length (cm) and pod width (cm). Secateurs were used to carefully dissect the pods by removing the capsule without crushing the seeds, to be able to identify what the insects inside. Finally, the internal sections of pods were visually examined for evidence of insect feeding with the aid of a hand lens. After a thorough examination, seeds without insect exit holes were classified as healthy, seeds with insect exit holes were classified as damaged, and those completely empty or shrunken and/or wrinkled were classified as undeveloped. Therefore, the seeds in this study were classified into three categories: healthy, damaged and undeveloped (Fig. 3.20). Afterwards, the number of pods and seeds in each category were recorded. In addition, microphotographs of all specimens were taken from different angles with a microscope and digital camera. The specimens were then preserved in plastic jars containing 70 % isopropyl alcohol. All specimens were identified to species level by a taxonomist at Harran University, Şanlıurfa, Turkey.

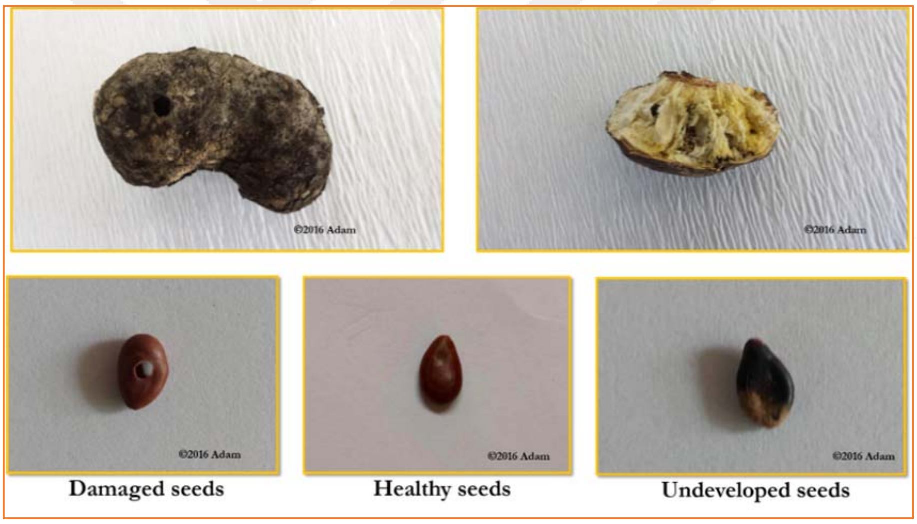

Figure 3.20. *Prosopis farcta* pods dissection, examination and seed categorization.

3.2.6.3. Statistical Analysis

Seed germination and dormancy breaking experiments were laid out in a completely randomized design with four replicates. Each experiment was conducted twice a year. Analysis of variance (ANOVA) indicated that there was no difference between the experiments conducted in each year. Therefore, each one-year data were combined for statistical analysis. Means were separated using

Fisher's least significant difference test (LSD) with the level of significance set at p = 0.05. The greenhouse experiments were arranged in a completely randomized split plot design with six replicates and the entire experiment was repeated twice (2017 & 2018). However, field experiments were laid out in a randomized complete block design (RCBD). Data of control percentage, plant height and biomass of each experiment were statistically analysed by one-way analysis of variance (ANOVA) using Minitab 18 software. Least significant differences (LSD) at 5% level of probability was run to separate between means. Data for infested and healthy pods and the total number of seeds per infested and healthy pod were analyzed with the SAS statistical software version 9.1.3 (SAS, 2004). To compare the differences in infestation rates among the three sites, the mean numbers of infested pods and the mean numbers of healthy pods were analyzed separately suing the Fisher's least significant difference test (LSD) with the level of significance set at p = 0.05.

4. RESULTS AND DISCUSSION

4.1. Temperature Requirements for Seed Germination of Two Mesquite Species

The results obtained from the germination experiment of the two mesquite species were given in the below subtitles.

4.1.1. Germination of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] Seeds

Temperature had significant effect on the germination percentage of dwarf mesquite seeds ($P < 0.05$). During the first and second year experiments, the germination percentages obtained at 30°C were 61% and 59.3%, respectively. The minimum, maximum and optimum temperatures required for dwarf mesquite seed germination were 20, 40, and 30°C, respectively. However, no seed was germinated at temperatures below 20°C and above 40°C (Fig. 4.1). In a study conducted by Ghaffarri et al., (2014) it's found that optimum temperature for seed germination of *P. farcta* was 30°C. Akkuzu, (2012) reported that the highest germination ratio was obtained at temperatures of 30 and 35°C. Şin et al., (2018) reported that the optimum temperature requiremenmt for the germination of *P. farcta* seeds was ranged between 30°C to 40°C.

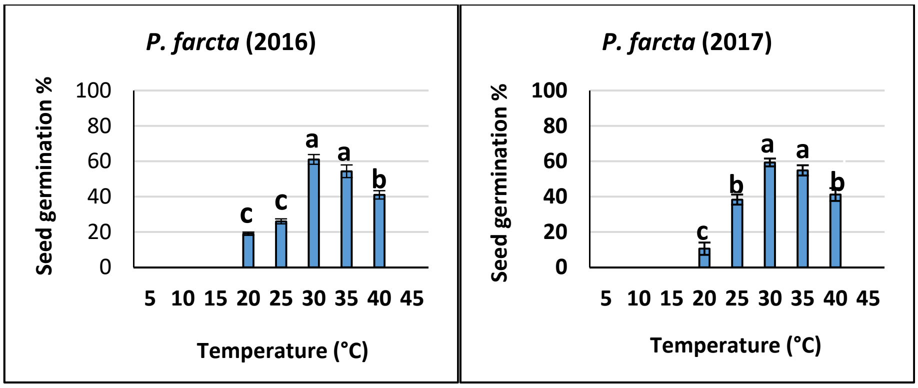

Figure 4.1. Percentage germination of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] seeds under different temperatures during two-year experiment (2016 and 2017). Means labelled with the same letter are not significantly different at p = 0.05.

4.1.2. Germination of Common Mesquite [*Prosopis juliflora* (Sw.) DC.] Seeds

At the end of the 28-day experiment, seeds were germinated in a considerably wide range of temperature (15 to 40 °C). Minimum, maximum and optimal temperature for common mesquite seed germination were 15°C, 40°C and 35°C, with germination percentages of 19%, 65% and 70%, respectively. Interestingly, germination reached 70% at the optimal temperature, indicating that common mesquite seed has a very low level of seed dormancy (Fig. 4.2). In a previous study, seeds of *P. farcta* was found to ideally germinate under a temperature range of 30-40°C (Şin et al., 2018).

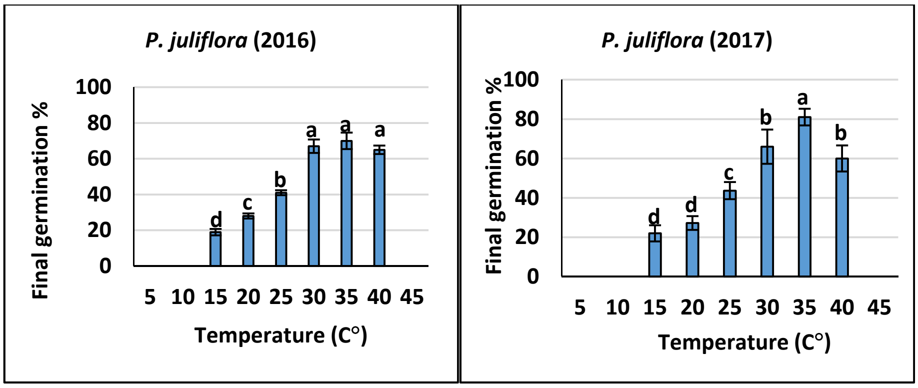

Figure 4.2. Percentage germination of common mesquite [*Prosopis juliflora* (SW.) DC.] seeds under different temperature degrees during the two-year experiments (2016 and 2017). Bars labelled with the same letter are not significantly different at p = 0.05.

4.2. Seed Dormancy Breaking

In the below subtitles, the results of seed dormancy breaking of the two mesquite were shown.

4.2.1. Dormancy Breaking in Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] Seeds

The final germination percentage of dwarf mesquite seeds subjected to pre-chilling at -5°C, pre-chilling at +5°C, preheating, seed coat cutting and untreated control were 42%, 54%, 38%, 100% and 61%, respectively. Both pre-chilling and pre-heating treatments showed less germination percentage than the untreated control. However, among all other treatments, the germination percentage obtained from physically scarified seeds was twice higher than that of pre-chilling and pre-heating treatments (Fig. 4.3). Ramezani et al., (2010) reported that seed cutting was significantly increased seed germination of *P. farcta*. In another study conducted by Majd et al., (2013) physical scarification using sandpaper and scalpel was found to be the most effective method to break seed dormancy in *P. farcta*, comparing to other mechanical and chemical treatments. As reported in many hard seeds (Crocker, 1906; Awan et al., 2014), seeds of dwarf mesquite, would be harshly scratched by larger-sized soil particles during tillage operations and might completely loss their physical dormancy. Şin et al., (2018) reported that the physical scarification was found to be effectively break the dormancy in the seeds of *P. farcta* and enhances its germination.

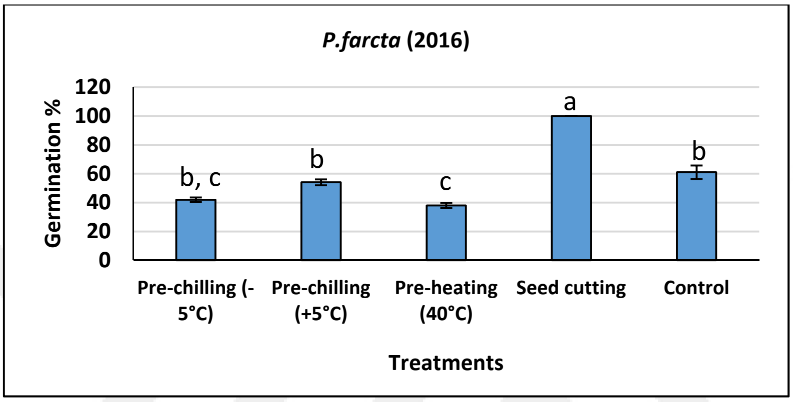

Figure 4.3. Effect of different treatments on germination of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] seeds under optimum temperature during the first year (2016). Means labelled with the same letter are not significantly different at p = 0.05.

In the second year experiment, the same level of effect on seed dormancy breaking has been shown by the different treatments. Final germination percentages of dwarf mesquite seeds exposed to pre-chilling at -5°C, pre-chilling at +5°C, preheating at 40°C, seed coat cutting and untreated control were 45.35%, 52.5%, 44.28%, 100% and 59.3%, respectively. A profound impact of seed coat cutting was shown in the two years of experiment, whereas slight difference in the effect of other pre-treatments between the first and second year was observed (Fig. 4.4).

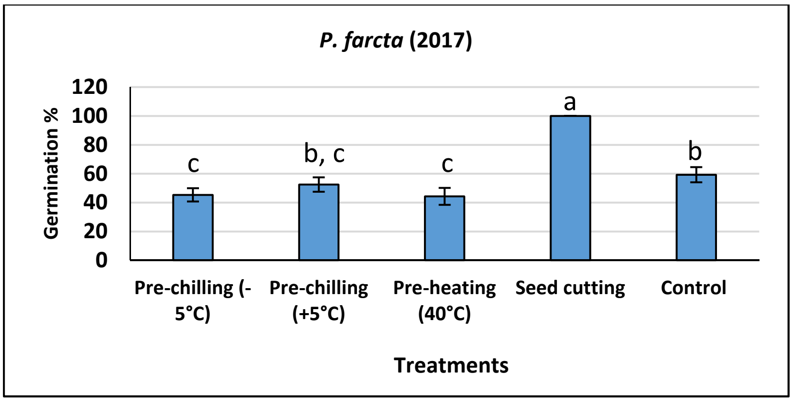

Figure 4.4. Effect of different treatments on germination of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] seeds under optimum temperature during the second year (2017). Means labelled with the same letter are not significantly different at p = 0.05.

4.2.2. Dormancy Breaking in Common Mesquite [*Prosopis juliflora* (Sw.) DC.] Seeds

The first year results showed that the overall germination percentages of common mesquite seeds exposed to pre-chilling at -5°C, pre-chilling at +5°C, preheating at 40°C, seed coat cutting and untreated control were 55%, 70%, 83%, 100% and 70%, respectively (Fig. 4.5). Except for pre-chilling treatments (at -5°C and +5°C), other treatments enhanced seed germination. In addition, among all treatments, only seed cutting technique showed the greatest germination percentage (100%). In a previous study, Pasiecznik, et al., (1998) reported more than 90% germination in *P. juliflora* seeds subjected to manual scarification, which considered effective method for breaking seed coat dormancy in common mesquite. Abbas et al., (2018) found that passing through the digestive track of the camel was fignificantly triggered germination of *P. juliflora* seeds. Because of its nutritious fruit, common mesquite has adapted to attract vertebrates and invertebrates consumers. Therefore, endozoochory would be the primary dispersal mechanism for *P. juliflora*, where animals may play a central role in seed dispersal and distribution of these invasive weeds both within time and space. According to a previous study performed by Rodrigues-Junior et al., (2019), pleurogram has been reported in 37 legume genera to be of a paramount importance in seed germination. Existence of pleurogram structure in seeds of *Prosopis* genus was reported in a couple of studies (Burkart, 1976; Irving, 1984; Serrato-Valenti et al., 1986; Werker, 1997). This specialized structure of seed is normally function as a water gap, which opens during dormancy break, allowing water to enter the seed (Baskin, et al., 2000; Baskin, 2003). In contrast, our study propose that pleurogram in *P. juliflora* seeds plays a crucial role in its germination process.

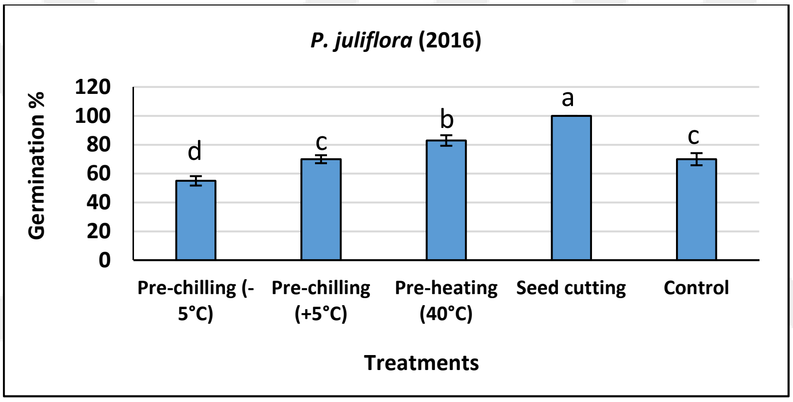

Figure 4.5. Effect of different treatments on germination of common mesquite [*Prosopis juliflora* (Sw.) DC.] seeds under optimum temperature during the first year (2016). Means labelled with the same letter are not significantly different at p = 0.05.

In the second year, the final percentages of common mesquite seed germination after application of pre-chilling at -5°C, pre-chilling at+5°C, preheating at 40°C, seed cutting and untreated control were 54%, 73.33%, 85%, 100% and 72%, respectively. Pre-chilling at -5°C has significantly (P<0.05) reduced seed germination. Seed cutting and preheating, by contrast, seemed to have the significant (P<0.05) effect on breaking the physical dormancy in common mesquite seeds (Fig. 4.6). Al-Rawahy et al., (2003) noticed that the seeds of *P. juliflora* were capable of germinating immediately after sowing and the germination percentage was significantly higher compared to the germination of the *P. sineraria* seeds. In addition, the researchers reported that the percentage germination of the untreated seeds of *P. juliflora* has been the same as that of the scarified seeds. MacDonald et al., (2002) applied variety of mechanical and chemical scarification methods to the *P. africana* Guill and Peri in order to break the seed dormancy and to assess the seed vigor. As a result, the highest germination ratio was obtained for P. Africana pretreated with ethanol for 10 minutes.

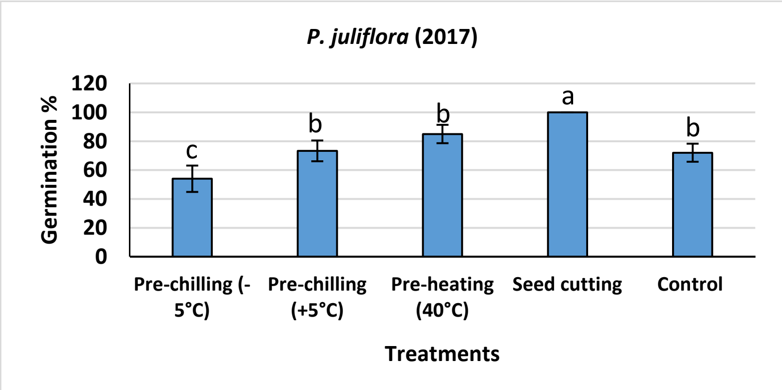

Figure 4.6. Effect of different treatments on germination of common mesquite [*Prosopis juliflora* (Sw.) DC.] seeds under optimum temperature during the second year (2017). Means labelled with the same letter are not significantly different at p = 0.05.

4.3. Chemical Control of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], under Greenhouse Conditions

4.3.1. Percentage Control of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.]

4.3.1.1. Effect of Glyphosate Diammonium

In this research, the biological effect of glyphosate diammonium on the dwarf mesquite shoot was observed within three days after application. In the first two weeks after herbicide treatment, there was a significant difference ($P<0.05$) in percentage control between the three doses. However, the differences between herbicides in terms of efficacy has been decreased from the third week forward.

During the first year, application of glyphosate diammonium at ½ N (1696 g a.i. ha^{-1}), 2/3 N (2261g a.i. ha^{-1}) and N (3392 g a.i. ha^{-1}) rates resulted in (30.83%, 42.5% and 57.66%); (42.16%, 75.66% and 92.66); (86%, 95% and 100%); (93.83%, 98.33% and 100%); and (100%, 98.33% and 100%) mesquite control in the first, second, third, fourth and eighth WAT, respectively (Fig. 18). In the second year, application of glyphosate diammonium at ½ N, 2/3 N and N rates resulted in (25.83%, 40.5% and 60.66%); (44%, 79.66% and 96.66%); (71%, 91% and 100%); (90.83%, 98.33% and 100%) and (90%, 98.33% and 100%) mesquite control in the first, second, third, fourth and eighth week, respectively (Fig. 4.7). Ganie et al., (2017) suggested that glyphosate absorption and translocation has been improved at higher temperatures and this study may confirms these results.

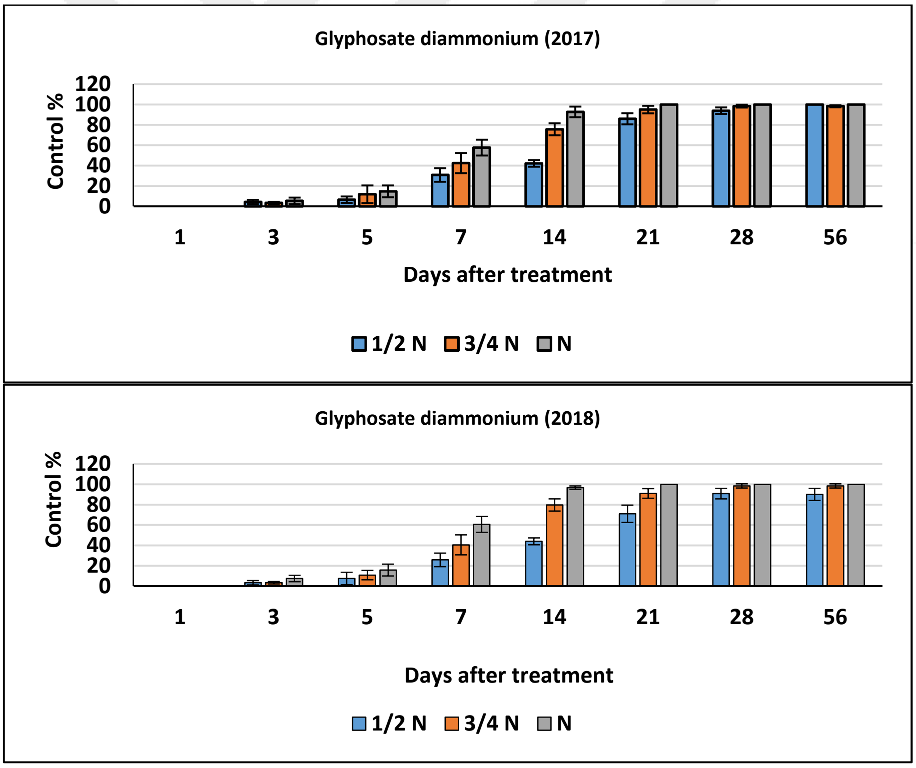

Figure 4.7. Percentage control of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], achieved by 424 g/l glyphosate di-ammonium salt applied at three doses (1/2 N, 2/3 N and N) during two-year greenhouse experiment (2017 and 2018).

4.3.1.2. Effect of glyphosate potassium salt

Similarly, glyphosate potassium salt showed visible symptoms on dwarf mesquite shoot system after three days of its application. In the first year, application of glyphosate potassium at the volume of ½ N (1984 g a.i. ha^{-1}), 2/3 N (2646 g a.i. ha^{-1}) and N (3969 g a.i. ha^{-1}) rate, achieved 14.16, 30.5 and 70% in the first week and 18%, 65% and 90.5% mesquite control in the second week, respectively, with significant differences ($P<0.05$) between ½ N, 2/3 N and N doses. In the second year, the same herbicide doses achieved 13.24, 33.33 and 70 percent weed control in the first week and 19.16, 68.33 and 96.5% mesquite control in the second week, with significant differences ($P<0.05$) between doses. In a study conducted by Singh and Singh, (2004) it was reported that the application of glyphosate on twelve weed species caused less reduction in plant growth compared to trifloxysulfuron. In a previous study, Bentivegna et al., (2017) found that the application of glyphosate on weeds at early and advanced growth stages was been effective enough to reduce plant shoot height but did not kill the plant. Similarly, we found that the herbicide seemed to be effective against dwarf mesquite at early growth stages (Fig. 4.8).

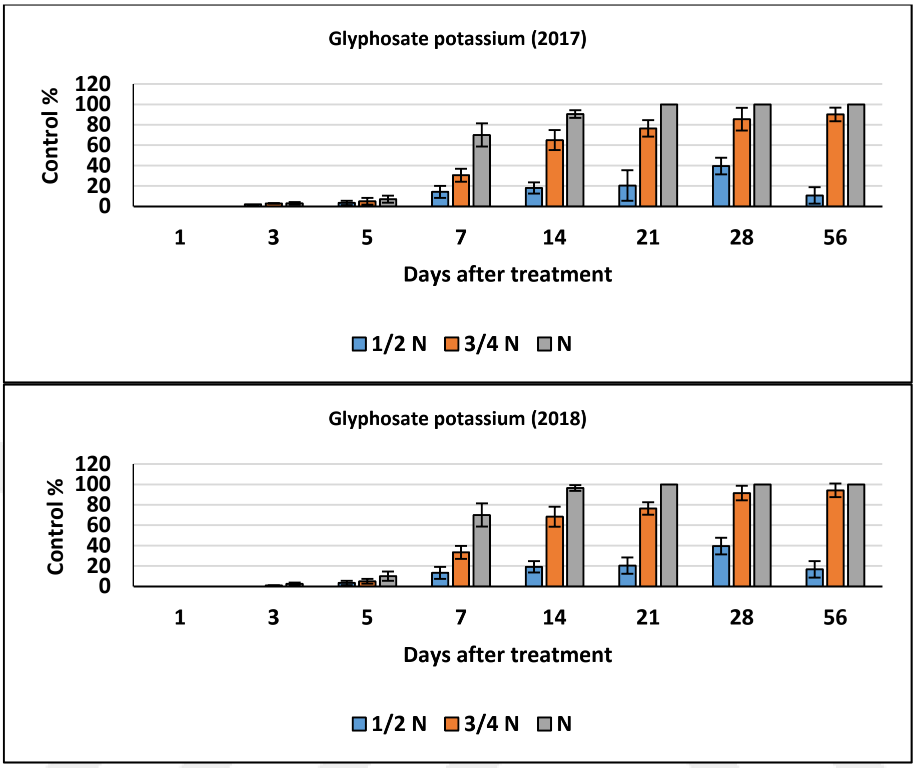

Figure 4.8. Percentage control of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], caused by 441 g/l glyphosate potassium salt applied at three doses (1/2 N, 2/3 N and N) during two-year greenhouse experiment (2017 and 2018).

4.3.1.3. Effect of Glufosinate Ammonium Salt

In the first and second year of the experiment, symptoms of glufosinate application seemed on dwarf mesquite just one day after treatment. Glufosinate provided effective weed control after two weeks after herbicide application with percentage control of 85.33%, 91.5% and 91.5% for ½ N (750 g a.i. ha^{-1}), 2/3 N (1000 g a.i. ha^{-1}) and N (1500 g a.i. ha^{-1}) doses.. Patra et al., (2016), reported that the glufosinate was effective against many weed species with its reduced doses. Similarly, in this study, all doses achieved complete control (100%) by the end of the experiment (4.9).

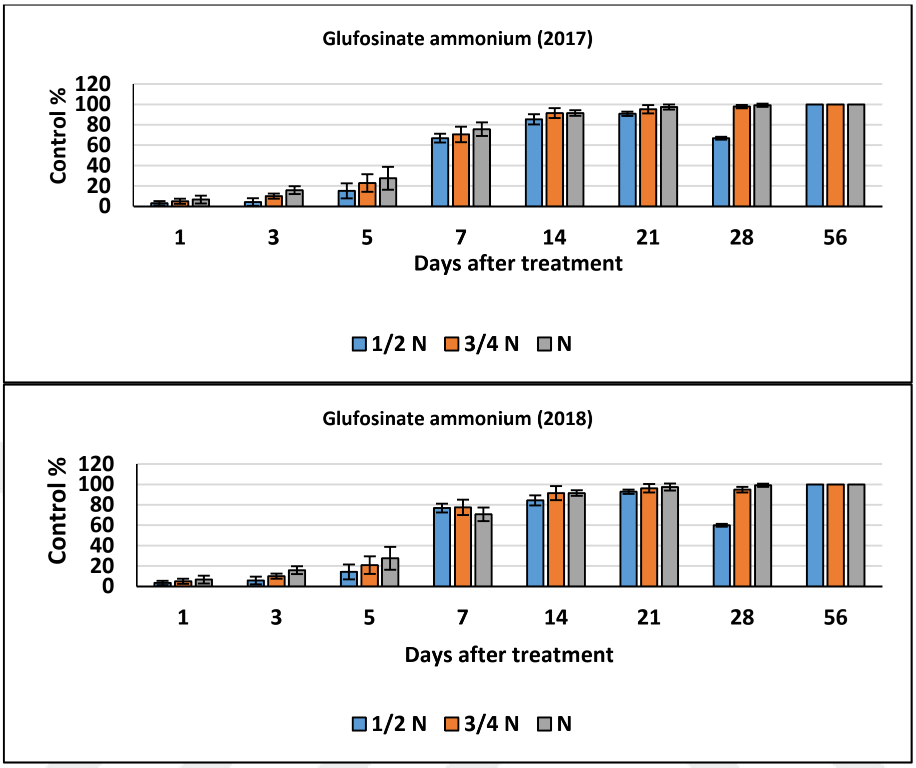

Figure 4.9. Percentage control of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], provided by 200 g/l glufosinate ammonium applied at three doses (1/2 N, 2/3 N and N) during two-year greenhouse experiment (2017 and 2018).

4.3.1.4. Effect of 2,4-D Amine Salt

Except for the recommended dose (N) the effect of 2,4-D amine on dwarf mesquite was not significant (P>0.05) until the third week of the experiment. In the first year, the percentage control achieved by ½ N (750 g a.i. ha^{-1}), 2/3 N (1000 g a.i. ha^{-1}) and N (1500 g a.i. ha^{-1}) was 33%, 37.12% and 40.83% in the first week, 43.33%, 53.33% and 75. 83% in the second week, respectively. Although the label recommended dose N has been the most effective dose from the beginning of the experiment, 100% control was observed with the three doses at the end of the experiment. In the second year, the herbicidal effect started early in the first week and increased continuously until reached its highest level on the 56th day of the experiment. Qasem, (2007), reported the 2,4-D mine to be effective against dwarf mesquite. However, the half dose of the herbicide provided relatively effective control, particularly in the effect provided in the first experiment (Fig. 4.10).

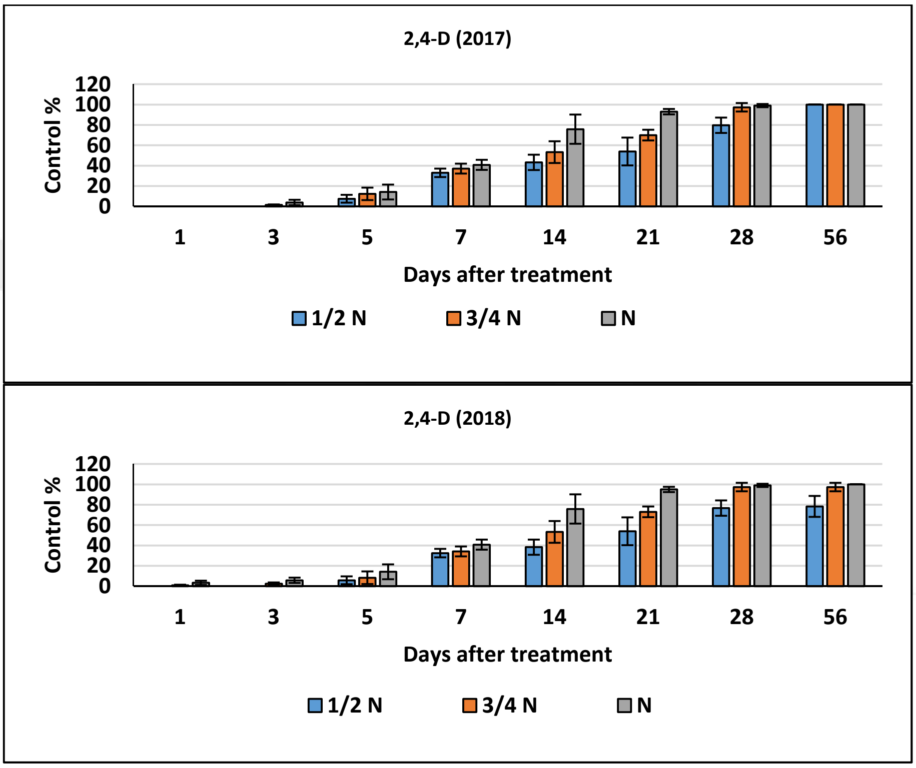

Figure 4.10. Percentage control of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], achieved by 500 g/l 2,4-D amine salt applied at three doses (1/2 N, 2/3 N and N) during two-year greenhouse experiment (2017 and 2018).

4.3.1.5. Effect of 2,4-D Triisopropylamine + Picloram

Significant effect on dwarf mesquite was observed one day after herbicide application. In the first year, the premix herbicide caused 100, 100 and 100% mesquite control with ½ N (2838 g a.i. ha^{-1}), 2/3 N (3784 g a.i. ha^{-1}) and N (5677 g a.i. ha^{-1}) rates, respectively. In the second year, similar effect was observed with the three doses. Interestingly, 2,4-D + picloram inhibited the regrowth of dwarf mesquite throughout the experiment (Fig. 4.11).

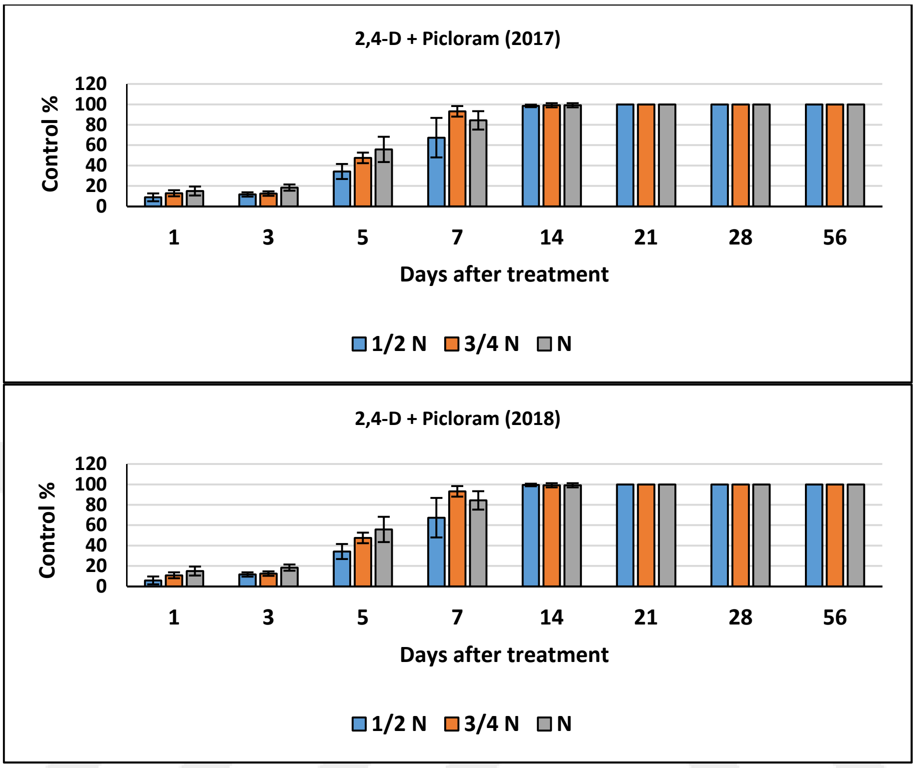

Figure 4.11. Percentage control of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], caused by 2,4-D tri-isopropylamine salt + picloram applied at three doses (1/2 N, 2/3 N and N) during two-year greenhouse experiment (2017 and 2018).

4.3.1.6. Comparative Percentage Control of Dwarf Mesquite (*P. farcta*)

In the first year, except glyphosate diammonium, all herbicides showed biological effects on dwarf mesquite immediately after the day of herbicides application. However, the most visible effect was observed in picloram treatment, especially in the recommended and two-third dose. In the second year the two glyphosate formulation had no effect on the first day (Fig. 4.12).

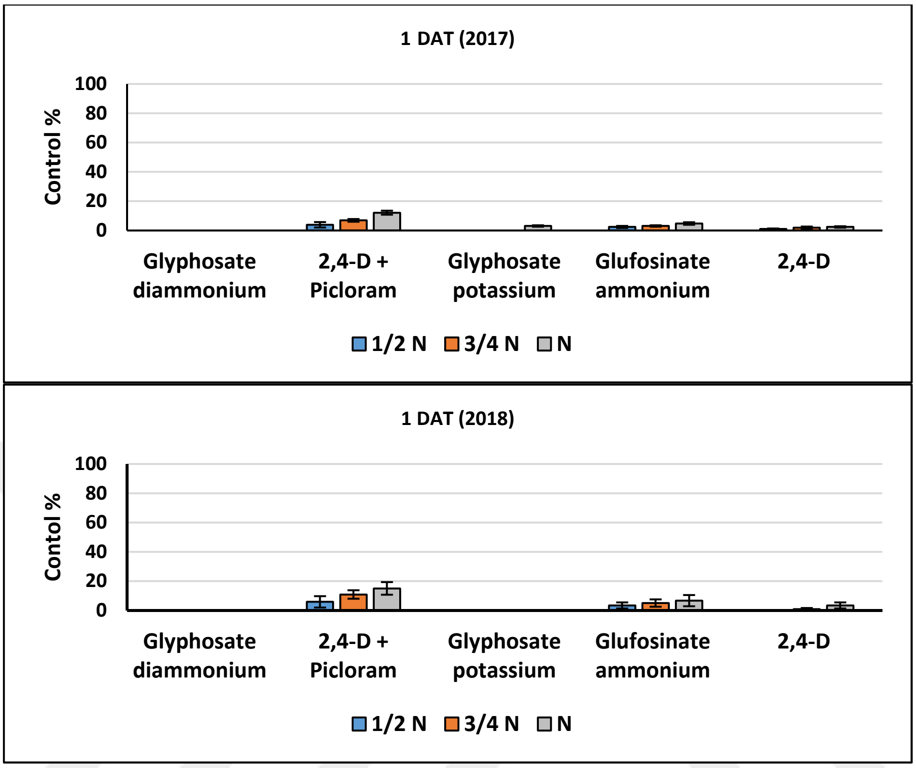

Figure 4.12. Effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied at three doses on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], under greenhouse conditions at the first day after herbicide application of two-year experiment (2017 and 2018).

On the third day of the first year, the highest control was provided with picloram, followed by glufosinate ammonium, glyphosate diammonium and 2,4-D, while the lowest effect was observed in glyphosate potassium. In the second year, compared to other herbicide treatments, picloram and glufosinate provided the highest control with their three doses (4.13).

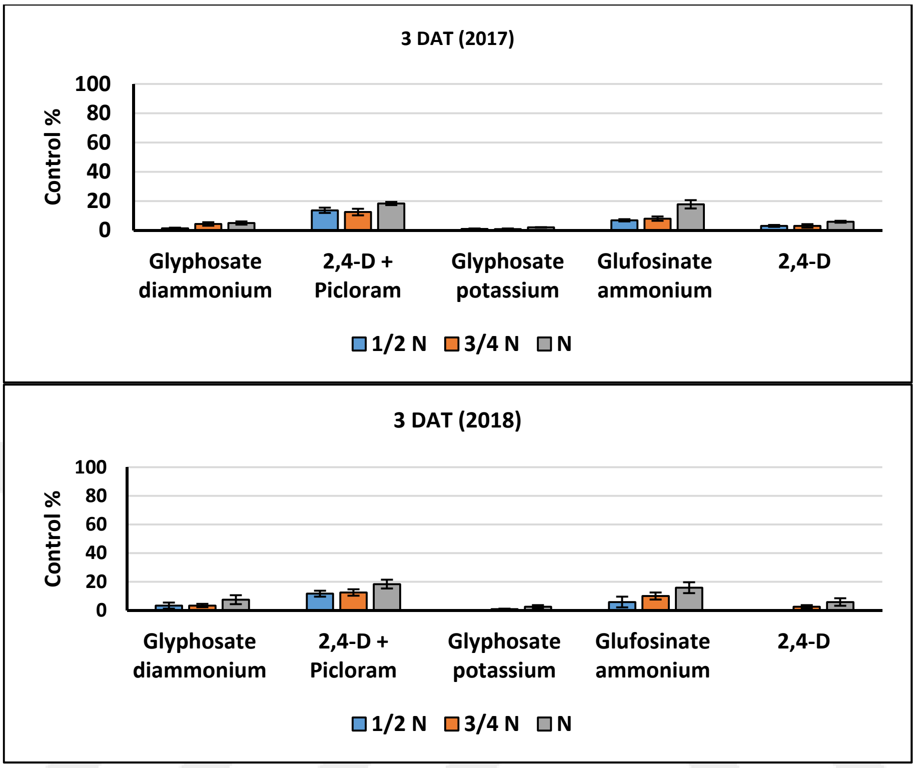

Figure 4.13. Effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied at three doses on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], under greenhouse conditions at the third day after treatment of two-year experiment (2017 and 2018). Means labelled with the same letter are not significantly different at p = 0.05.

On the fifth day after herbicide application, visible, but not efficient, symptoms were found in all herbicide treatments during 2017 experiment. However, there was a significant difference among the herbicide treatments and doses in terms of herbicidal activities. Throughout the two year experiments, the efficacy of picloram has been continuously greater than other herbicides (Fig. 4.14).

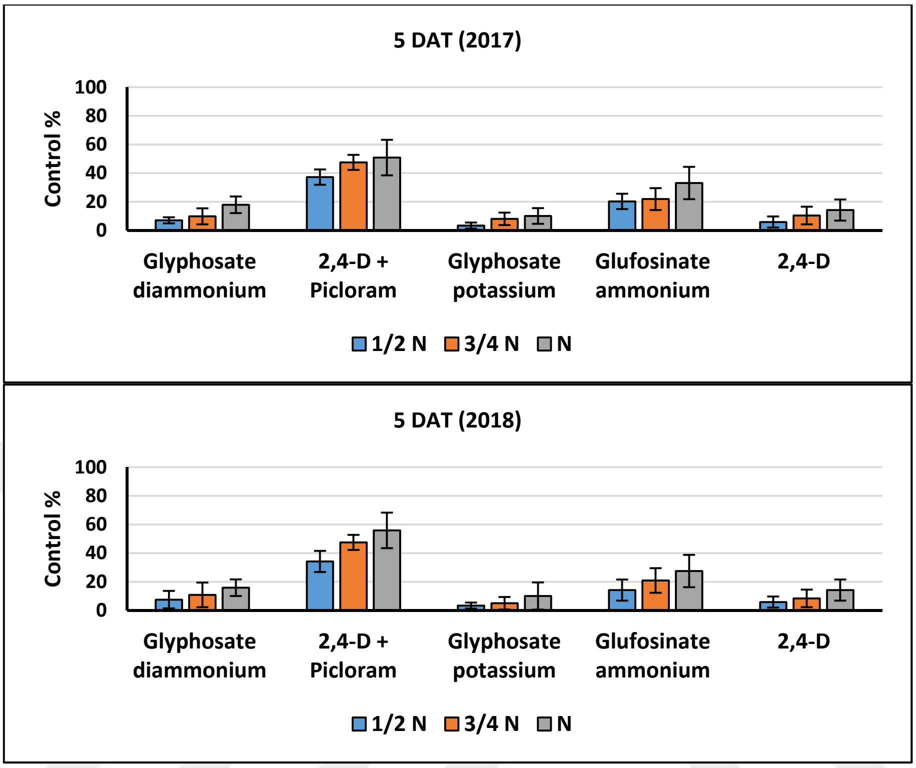

Figure 4.14. Effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], under greenhouse conditions at the fifth day after herbicide application of a two-year experiment (2017 and 2018). Means labelled with the same letter are not significantly different at p = 0.05.

For the 2017 experiments, percentage dwarf mesquite control achieved by the five herbicides in their label recommended dose (N) in the first week after treatment was 65.66, 94.33, 65, 77.06 and 50% for glyphosate diammonium, 2,4-D + picloram, glyphosate potassium, glufosinate ammonium and 2.4-D amine, respectively. Whereas in the 2018 experiment, the recommended doses of glyphosate diammonium, 2,4-D+picloram, glyphosate potassium, glufosinate ammonium and 2.4-D amine were found to provide 60.66, 92.28, 70, 70.66 and 40.83, respectively (Fig. 4.15).

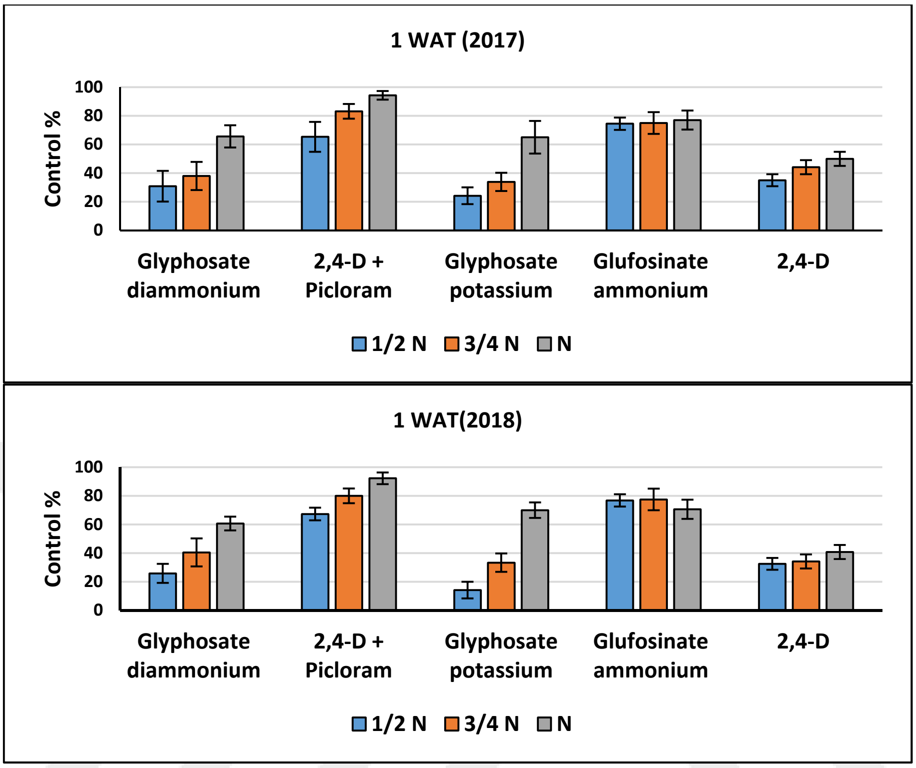

Figure 4.15. Effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], under greenhouse conditions at the first week after herbicide application of two-year experiment (2017 and 2018). Means labelled with the same letter are not significantly different at p = 0.05.

The effect of the premix herbicide, 2,4-D+picloram was clearly observed on dwarf mesquite through the typical symptoms of chlorosis and and growth distortion. While extreme stem malformation, leaf crinkling, epinasty and leaf strapping have were observed on dwarf mesquite seedlings treated with 2,4-D amine. Seedlings treated with glyphosate and glufosinate herbicides have shown visible symptoms such as leaf narrowing and stunting (Fig. 4.16).

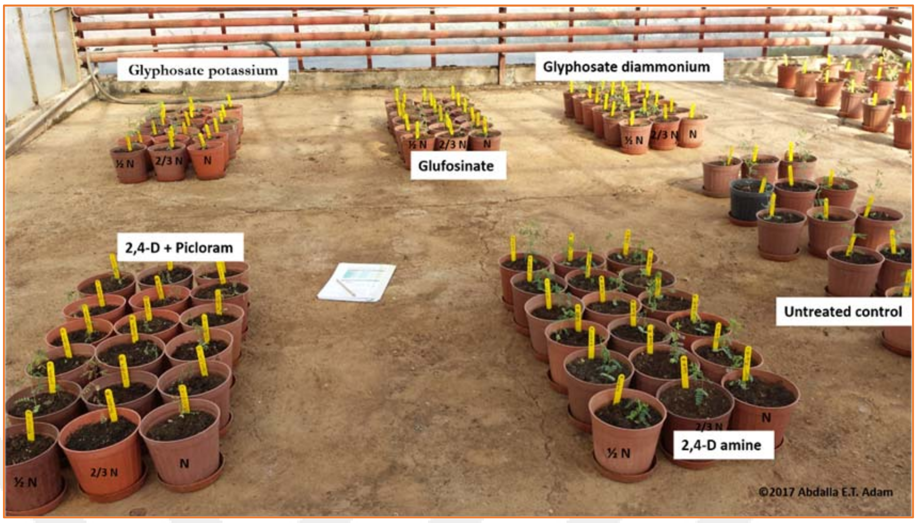

Figure 4.16. Effect of five herbicides applied in ½ N 2/3 N and N doses on greenhouse-grown dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], after one week of herbicide application**.**

In the second week of the experiment of 2017, results showed significant injury to dwarf mesquite. By contrast, there was no significant difference ($P<0.05$) in response to the premix herbicide, 2,4-D+picloram at all tested doses. During the 2018 experiment, the same effect was observed when all doses provided excellent mesquite control during the second weed of the experiment. Glufosinate ammonium was observed to achieve the second highest control percentage, with its three application rates. In addition, there was a slight increase in the efficacy of glufosinate ammonium at the two-third and the half doses (Fig. 4.17)

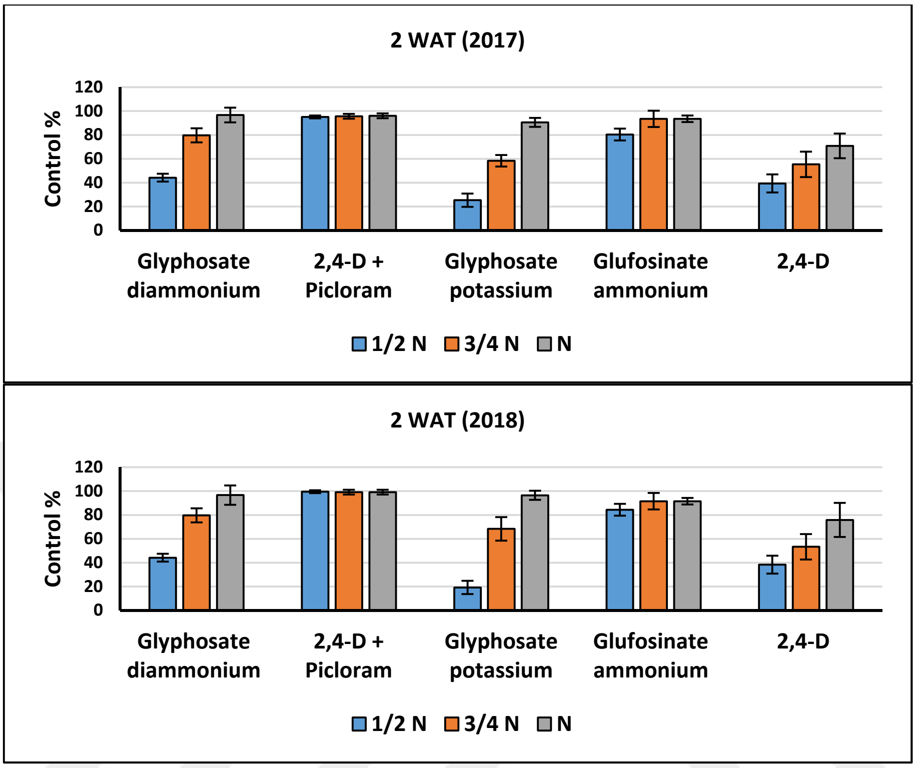

Figure 4.17. Effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D+picloram) applied in three doses on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], under greenhouse conditions at the second week after herbicide application of two-year experiment (2017 and 2018).

On the second week of experiment, mesquite plants subjected to and 2,4-D plus picloram were completely killed. Whereas severe defoliation was observed on dwarf mesquite plants treated with glufosinate herbicide. Glyphosate diammonium provided significant damage to *P. farcta* compared to glyphosate potassium. Plants sprayed with 2,4-D amine showed twisted stems and distorted growth, which seemed least likely to recover (Fig. 4.18).

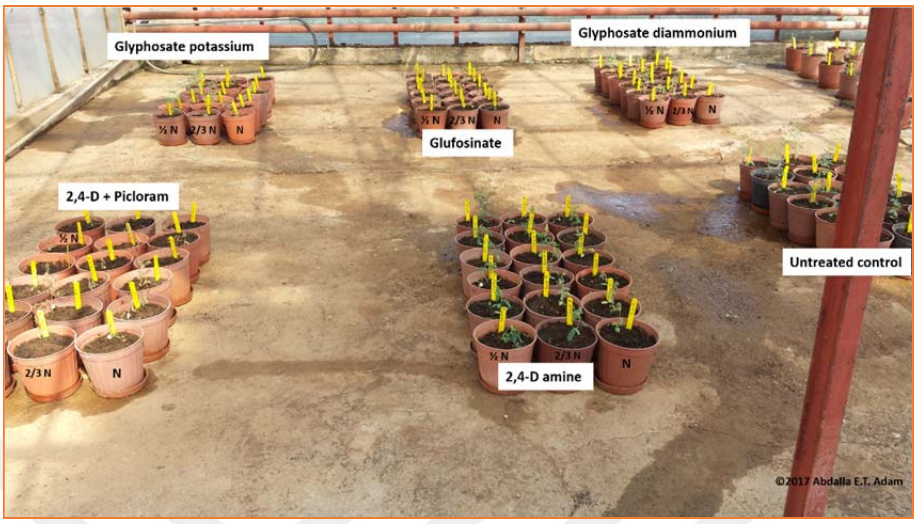

Figure 4.18. Effect of five hervicides applied in ½ N 2/3 N and N doses on greenhouse-grown dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], after two weeks of herbicide application.

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In the third week of the first experiment (2017), 2,4-D+picloram and glufosinate ammonium achieved 100% mesquite control at the three doses. However, 100, 92.5 and 87% control was observed in the recommended doses of glyphosate potassium, glyphosate diammonium and 2,4-D amine treatments, respectively. In the second experiment, all doses of 2,4-D+picloram provided the same control percentage (100%) while the N, 2/3 N and ½ N of glufosinate diammonium provided 97.4, 96.2 and 92.8% control, respectively. However, the herbicidal effects of the recommended doses of glyphosate potassium, glyphosate diammonium and 2,4-D amine were slightly increased (Fig. 4.19)

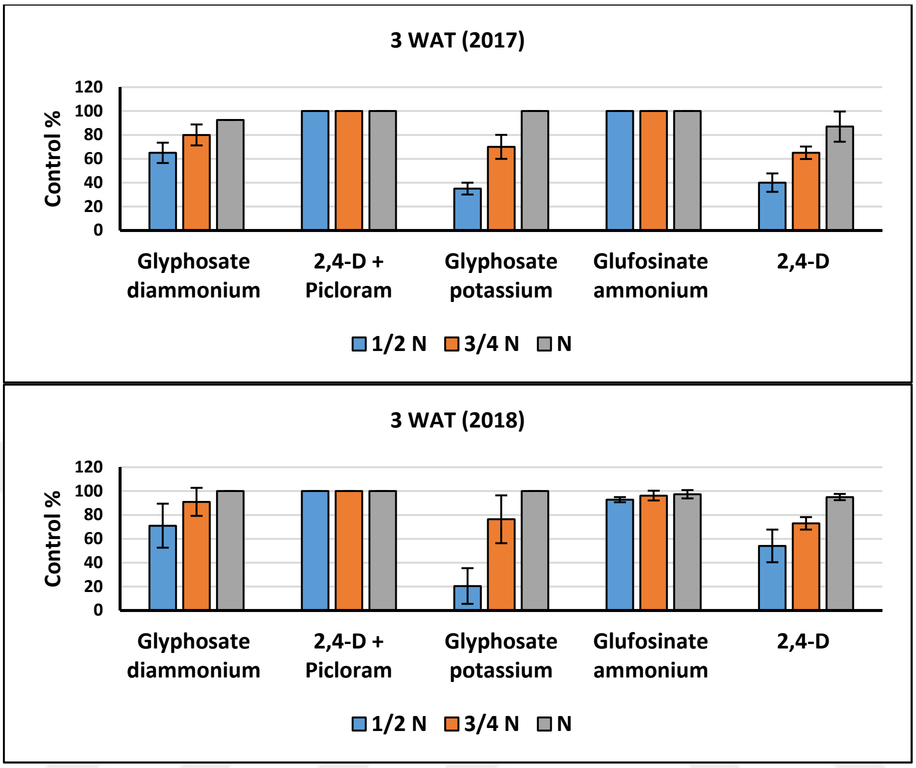


Figure 4.19. Effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D+picloram) applied in three doses on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], under greenhouse conditions at the third week after herbicide application of two-year experiment (2017 and 2018).

During the third week, the three doses of the premix herbicide and glufosinate were successfully controlled dwarf mesquite. Glyphosate potassium has been effective only at its recommended rate. Glyphosate diammonium and 2,4-D amine provided the same control level. Severe leaf distortion and leaf stunting symptoms were observed on plant treated with glyphosate-based fomulations. Glufosinate ammonium application resulted in very clear necrotic spots on drawf mesquite. Leaf curling and malformation have obviously shown over plants treated with 2,4-D amine. Symptoms such as pinasty and leaf crinkling were ovserved on seedling exposed to picloram herbicide (Fig. 4.20).

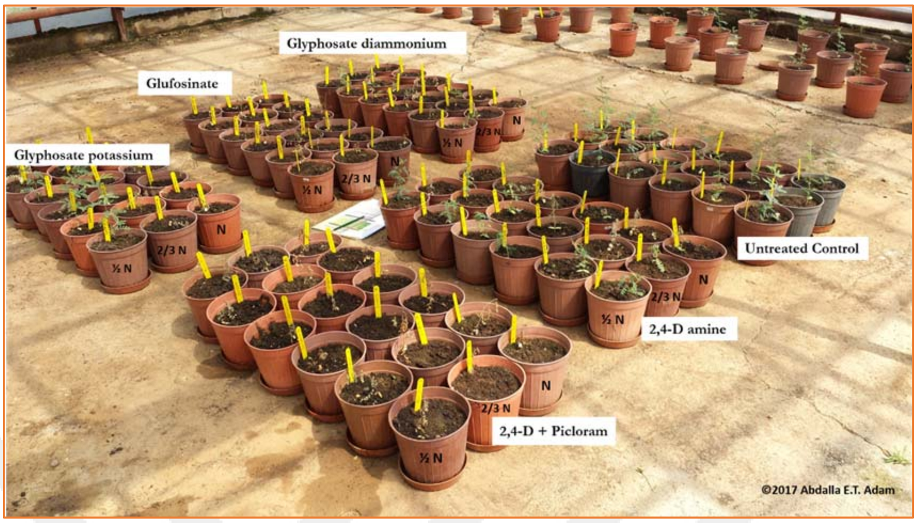


Figure 4.20. Effect of five herbicides applied in ½ N 2/3 N and N doses on greenhouse-grown dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], after three weeks of herbicide applications.

During the fourth week, the premix herbicide, 2,4-D+picloram, was the only herbicide controlled 100% of *P. farcta* at its three doses, both in 2017 and 2018 experiments. In 2017, recommended and two-third doses of 2,4-D and glyphosate diammonium achieved (100%, 100%) and (90%, 88.33%) mesquite control, respectively. In 2018, plants treated with recommended and two-third rates of 2,4-D and glyphosate diammonium have showed (99%, 97.33%); and (100%, 98.33%) mesquite control, respectively. Application of glufosinate ammonium and glyphosate potassium provided 95.46% and 90% mesquite control in 2017 at their recommended doses. In the 2018 experiment, application of glufosinate and glyphosate potassium provided 99.16%, 67.83% and 99.83; and 100%, 91.5% and 39.5% at their recommended, two-third and half doses, respectively (Fig. 4.21).

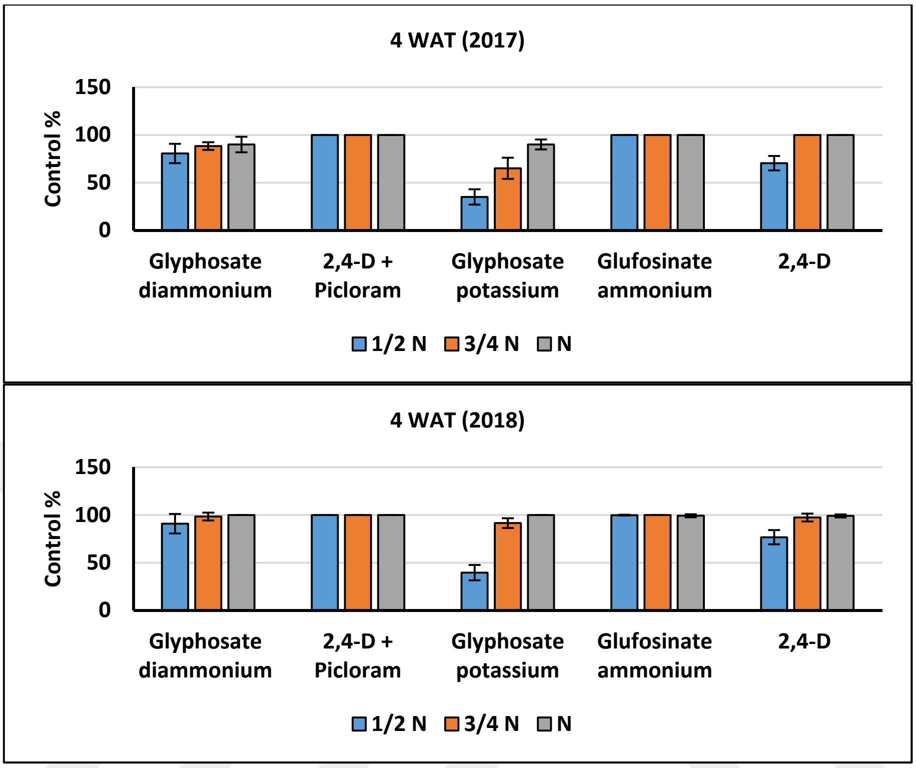


Figure 4.21. Effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D+picloram) applied in three doses on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], under greenhouse conditions at the fourth week after herbicide application of two-year experiment (2017 and 2018).

As shown below, dwarf mesquite seedlings exposed to picloram, glufosinate and glyphosate di-ammonium herbicides were completely killed. Symptoms such as epinasty, stem malformation and twisting were obviously observed on plants treated with 2,4-D amine (Fig. 4.22).

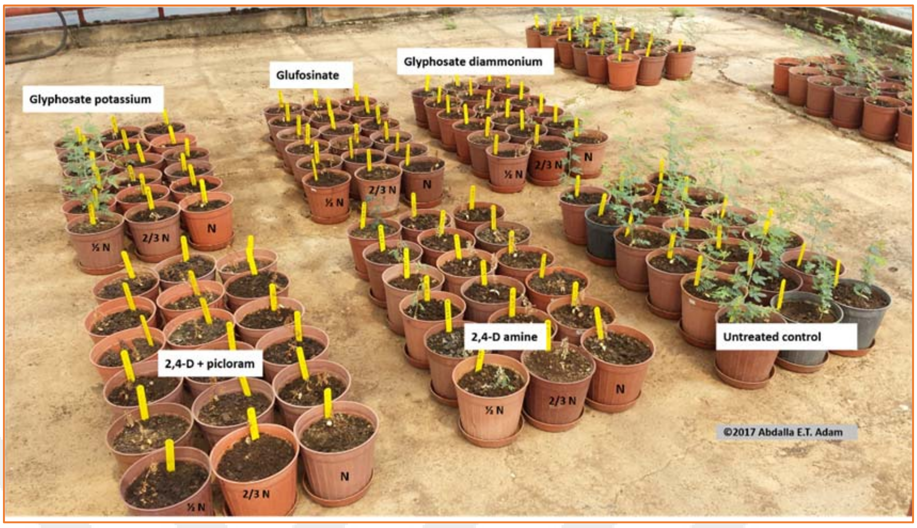


Figure 4.22. Effect of five herbicides applied in ½ N 2/3 N and N doses on greenhouse-grown dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], after four weeks of herbicide application.

Interestingly, by the end of the experiment, glufosinate ammonium achieved as same percentage control (100%) of mesquite in the two years with its three doses as 2,4-D+picloram herbicide. In addition, recommended dose and two-third dose treatments of glyphosate diammonium, glyphosate potassium and 2,4-D amine provided (100%, 92.33%); (100%, 100%); and (100%, 94.33%) mesquite control in 2017 and (100%, 98.33%); (100%, 94.16%) and (100%, 97.33%) mesquite control in 2018, respectively (Fig. 4.23).

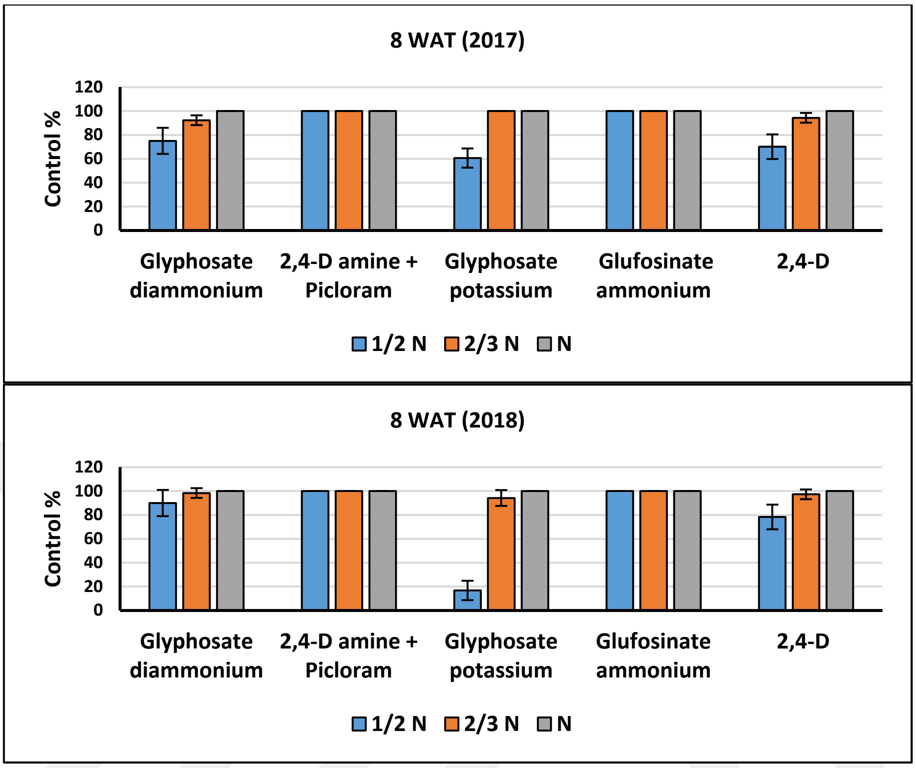


Figure 4.23. Effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D+picloram) applied in three doses on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], under greenhouse conditions at eighth week after treatment during two-year experiment (2017 and 2018).

At the end of the experiment, except glyphosate potassium, all herbicides were effectively controlled *P. farcta*. Typical growth regulator symptoms were seen on dwarf mesquite seedling after exposed to 2,4-D application (Fig. 4.24).

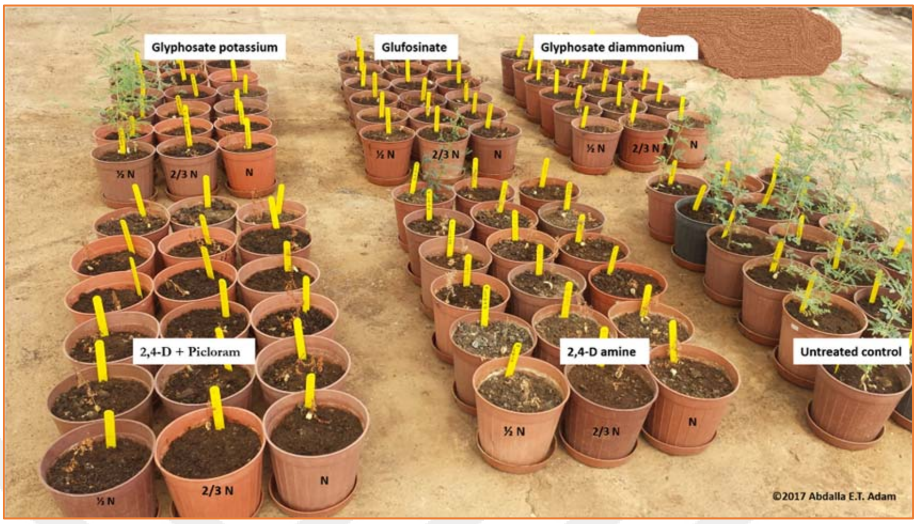


Figure 4.24. Effect of five herbicides applied in ½ N 2/3 N and N doses on greenhouse-grown dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], after eight weeks of herbicide treatments.

4.3.2. Effect of Herbicides on Growth of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.]

4.3.2.1. Effect of Glyphosate Diammonium

In the 2017 study, glyphosate diammonium provided 100%, 99.45, 94.05% and 100% reduction in dwarf mesquite growth at its recommended dose (3392 g a.i. ha^{-1}) in the 2^{nd}, 3^{rd}, 4^{th} and 8^{th} WAT, respectively. At two-third dose (2261 g a.i. ha^{-1}), the reduction in the plant growth was observed to be 70.43%, 95%, 82.87% and 90.5% in the 2^{nd}, 3^{rd}, 4^{th} and 8^{th} WAT, respectively. In contrast, when the herbicides were applied at half dose (1696 g a.i. ha^{-1}), plant growth was reduced by 50.05%, 71%, 80% and 85.34% in the second, third, fourth and eighth week WAT, respectively. In the 2018 study, relatively the same percentage control was observed at the recommended dose when 94.07, 98.23, 100 and 100% control were recorded on the 2, 3, 4 and 8 WAT, respectively. However, a considerable decline in herbicidal activity was observed in the half dose, indicating a poor foliar uptake with decreased doses. In addition, herbicide symptoms were observed on the mesquite plant two weeks after treatment, indicating slower overall efficacy of glyphosate diammonium. Beck et al. (1975) reported that, 2,4,5-T plus picloram was clearly more effective than 2,4,5-T amine and 2,4,5-T ester against mesquite (*Prosopis velutina*) particularly when applied on mesquite plants before pod maturity. (Fig. 4.25).

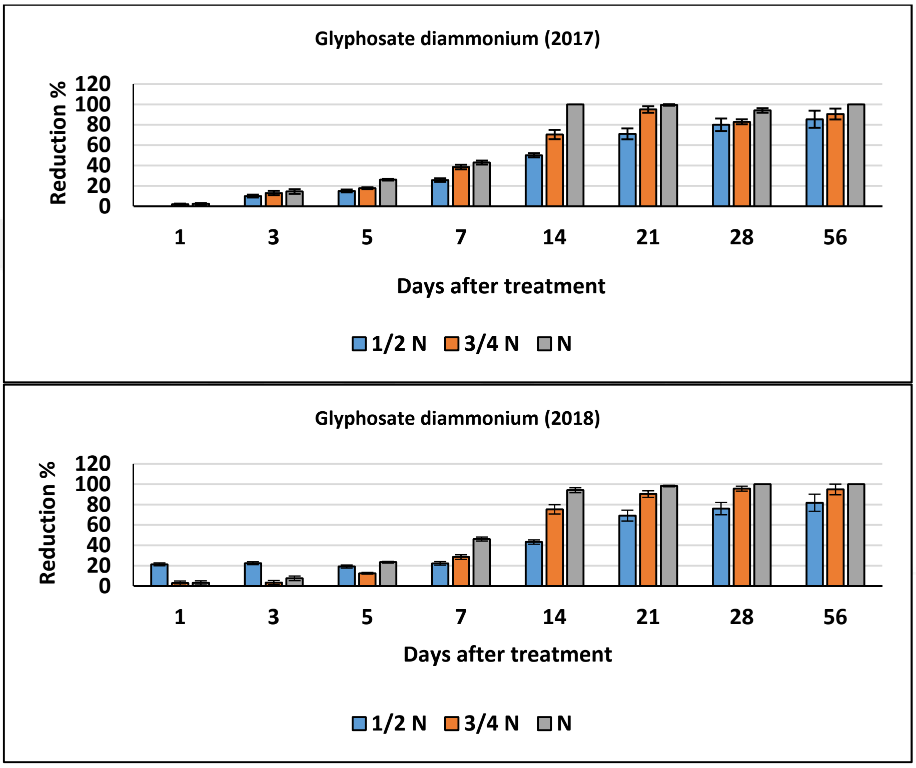


Figure 4.25. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] after application of 424 g/l glyphosate di-ammonium at three doses (1/2 N, 2/3 N and N) during a two-year greenhouse experiment (2017 and 2018).

4.3.2.2. Effect of Glyphosate Potassium Salt

In 2017 experiment, glyphosate potassium successfully controlled mesquite only at its recommended dose (3969 g a.i. ha^{-1}) with 95.01%, 100%, 100% and 100% control in the 2^{nd}, 3^{rd}, 4^{th} and 8^{th} WAT, respectively. However, application of glyphosate potassium at two-third dose (2646 g a.i. ha^{-1}) provided

50.33%, 69.8%, 76.84% and 97.23% mesquite control in the 2nd, 3rd, 4th and 8th WAT, respectively. Similarly in 2018 experiment, the recommended dose of glyphosate potassium resulted in 97.03%, 100%, 100% and 100% mesquite control in the second, third, fourth and eighth WAT, respectively. While the two-third dose provided 60.03%, 76.18%, 84.76% and 91.67% control on the 2nd, 3rd, 4th nd 8th week after treatment. However, throughout the two-year experiments, lowest mesquite control was observed in the half dose (1984 g a.i. ha^{-1}). Qasem, (2007), recommended the 2,4-D amine as an effective herbicide against *P. farcta*. However, our results indicate that the reduced doses of this herbicide were less effective against dwarf mesquite under field conditions (Fig. 4.26).

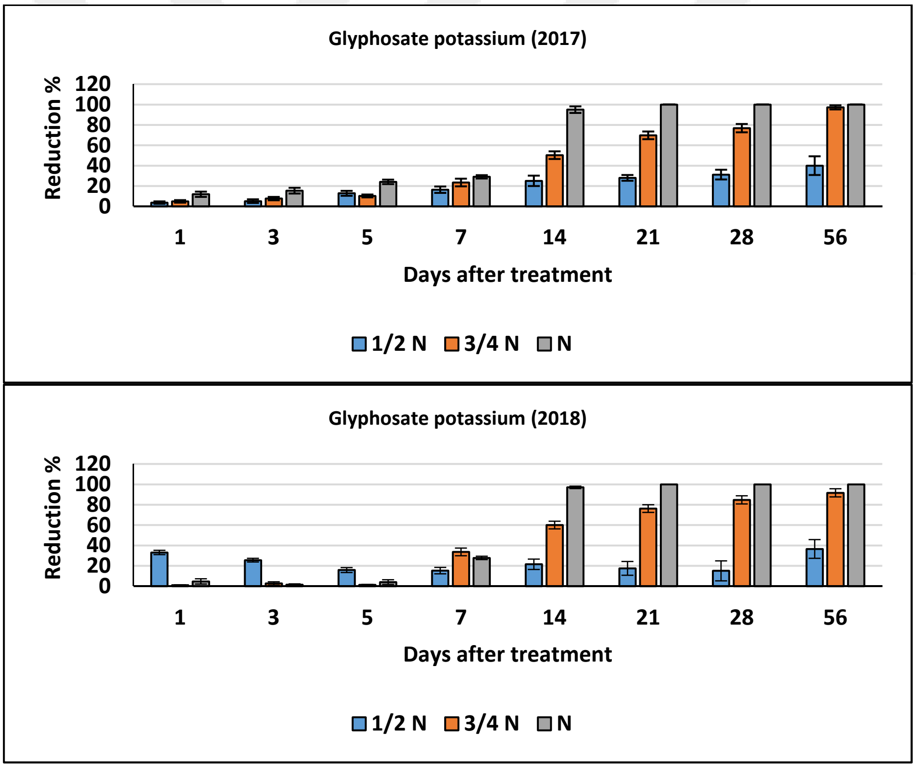


Figure 4.26. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] after application of 441 g/l glyphosate potassium at three doses (1/2 N, 2/3 N and N) during two-year experiment (2017 and 2018).

4.3.2.3. Effect of Glufosinate Ammonium

In the 2017 experiment, successful dwarf mesquite control was provided by the recommended dose (1500 g a.i. ha^{-1}) of glufosinate ammonium, when 85.29%, 100%, 100% and 100% mesquite control were observed in the second, third, fourth and eighth WAT, respectively. When the herbicide was applied at two-third dose (1000 g a.i. ha^{-1}), 66.56%, 95.97%, 95.97% and 100 % control was observed. This shows that there was no significant difference ($p>0.05$) between the recommended and two-third dose. In 2018, although there was a slight decline in herbicide effectiveness, all tested doses gave impressive control of dwarf mesquite. As reported by Patra et al. (2016), the half dose (750 g a.i. ha^{-1}) of glufosinate ammonium seemed to be biologically more effective than the two higher doses (Fig. 4.27).

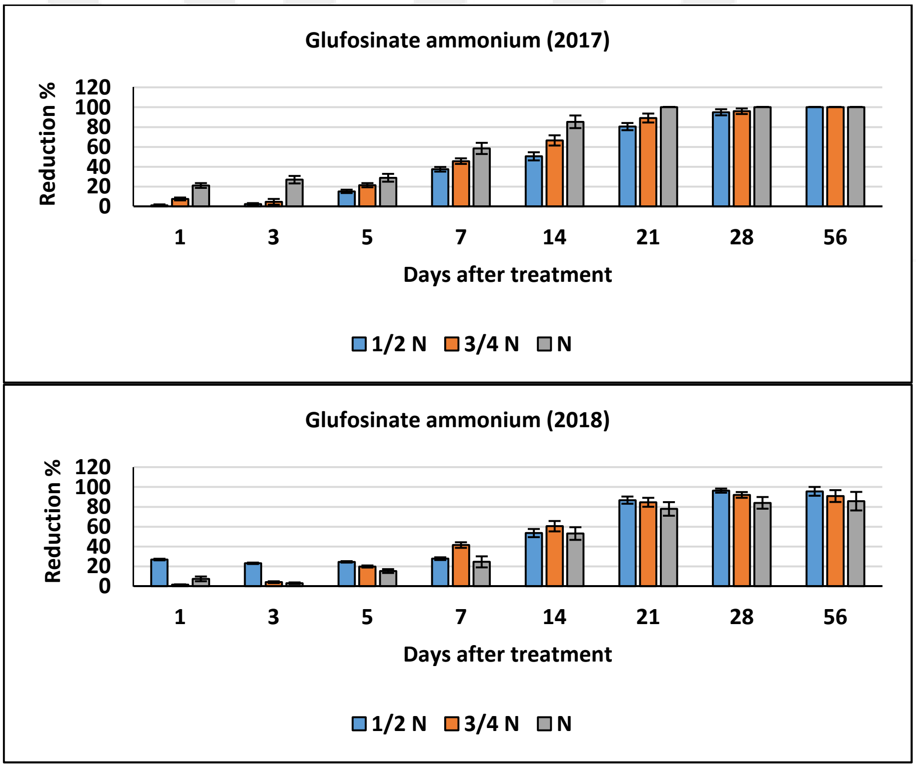


Figure 4.27. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] after application of 200 g/l glufosinate ammonium at three doses (1/2 N, 2/3 N and N) during two-year experiment (2017 and 2018).

4.3.2.4. Effect of 2,4-D Amine

In 2017, 2,4-D amine caused 70.48%, 85.85%, 100% and 100% reduction in dwarf mesquite growth at label recommended dose (1500 g a.i. ha^{-1}) in the 2^{nd}, 3^{rd}, 4^{th} and 8^{th} WAT, respectively. At two-third dose (1000 g a.i. ha^{-1}), 2,4-D amine reduced plant growth by 49.79%, 70.75%, 90.05% and 100% in the second, third, fourth and eighth week, respectively. Application of 2,4-D at half dose (750 g a.i. ha^{-1}) provided 44.25%, 51.58%, 59% and 89.83% by the second, third, fourth and eighth week of treatment, respectively. However, before the first two weeks after treatment, the herbicide was less (5 to 30% reduction) effective at all doses. From the third week forward, there were no significant differences ($p>0.05$) between the recommended dose and two-third dose in terms of efficacy. In the second experiment, 2018, the growth reduction resulted from of 2,4-D amine applied at label recommended dose was 65.36%, 70.89%, 92.01% and 100% in the second, third, fourth and eighth WAT, respectively. Likewise, the herbicide caused 49.17%, 67.36%, 89.11 and 100% reduction in plant growth in the second, third, fourth and eighth WAT, respectively. When half of the recommended dose was applied, plant growth was reduced by 39.3%, 41.78%, 59.37% and 100% in the 2^{nd}, 3^{rd}, 4^{th} and 8^{th} WAT, respectively. Although herbicide seemed less effective throughout the first two weeks, by the end of the experiment, 2,4-D amine was found to completely (100%) control dwarf mesquite with three tested doses (Fig. 4.28). Derr and Serensits (2016) and Ganie et al. (2017) reported that the higher temperature increased the 2,4-D effectiveness against broadleaf weeds compared to coll climate. Our research reaches the same conclusion as the temperature degrees have been high inside the greenhouse during the summer.

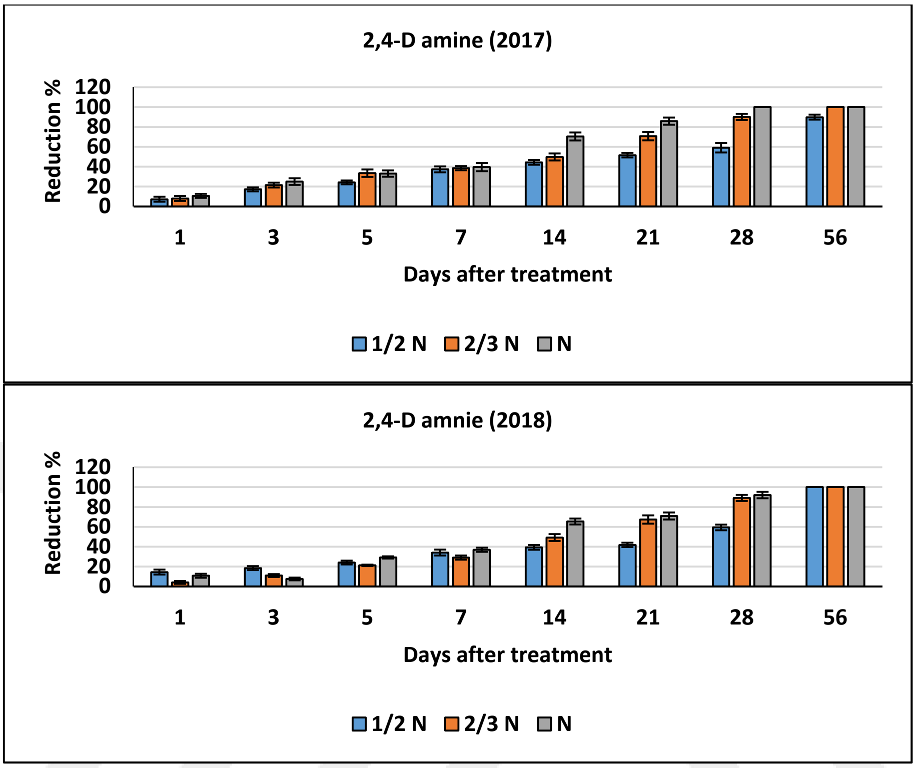


Figure 4.28. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] after application of 500 g/l 2,4-D amine at three doses (1/2 N, 2/3 N and N) during a two-year experiment (2017 and 2018).

4.3.2.5. Effect of 2,4-D Tri-isopropylamine + Picloram

The premix herbicide, 2,4-D+picloram, caused 75%, 97.06%, 100%, 100%, 100% and 100% reduction in dwarf mesquite growth at recommended dose (5677 g a.i. ha^{-1}); 70.77%, 95%, 95.32%, 100%, 100% and 100% at two-third dose (3784 g a.i. ha^{-1}); and 70.12%, 90.63%, 94.17, 100%, 100% and 100% at half dose (2838 g a.i. ha^{-1}) in the 5, 7, 14, 21, 28 and 56 DAT, respectively, in 2017 experiment (Fig. 4.29). This may indicate rapid biological activity caused by this premix herbicide just few days after its application. In 2018, application of recommended dose resulted in 74.83%, 100%, 87.17%, 100%, 100% and 100% reduction in plant growth, 5, 7, 14, 21, 28 and 56 days after herbicide application

(Fig. 4.29). Whereas two-thirds and half doses caused 74.83%, 97.63%, 95.06%, 92.94%, 100% and 100%; and 69.53%, 94.08%, 96.05%, 100%, 100% and 100% in the 5th, 7th, 21st, 28th and 56th days after treatment, respectively. For the two years, there were no statistically significant differences among the three dose in terms of their effect on plant growth, indicating that the half of the recommended dose is effective enough to provide the same weed control as that achieved by recommended one. Friesen and Dew, (1966) reported that the activity of picloram was increased when the soil moisture and air temperature was optimum to the buckwheat. . Feldman and Galvan, (1972) found the picloram+diesel or kerosene to be very effective against *Prosopis ruscifolia* when applied as stump cut herbicide.

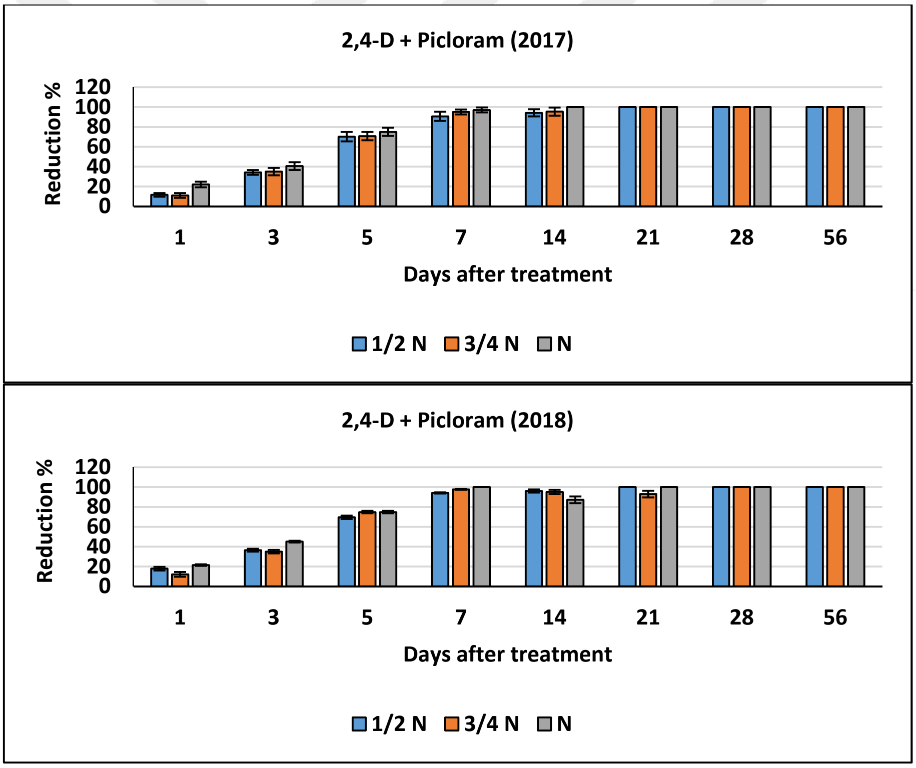


Figure 4.29. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] after application of 451.4 g/l 2,4-D tri-isopropylamine salt + 116.3 g/l picloram at three doses (1/2 N, 2/3 N and N) during a two-year experiment (2017 and 2018).

4.3.2.6. Comparative Effect on Dwarf Mesquite (*P. farcta*) Growth

For the 2017 experiment, all herbicides showed almost no visible effect on dwarf mesquite growth has been found on the first day after herbicide application. However, when the efficacy of herbicides was compared, 2,4-D plus picloram was found more effective than all other herbicide treatments. In 2018, the percentage reduction in plant growth seemed to be significantly lower than that observed in 2017. As reported by Patra et al. (2016), in this study, all reduced doses showed greater efficacy than higher doses (Fig. 4.30).

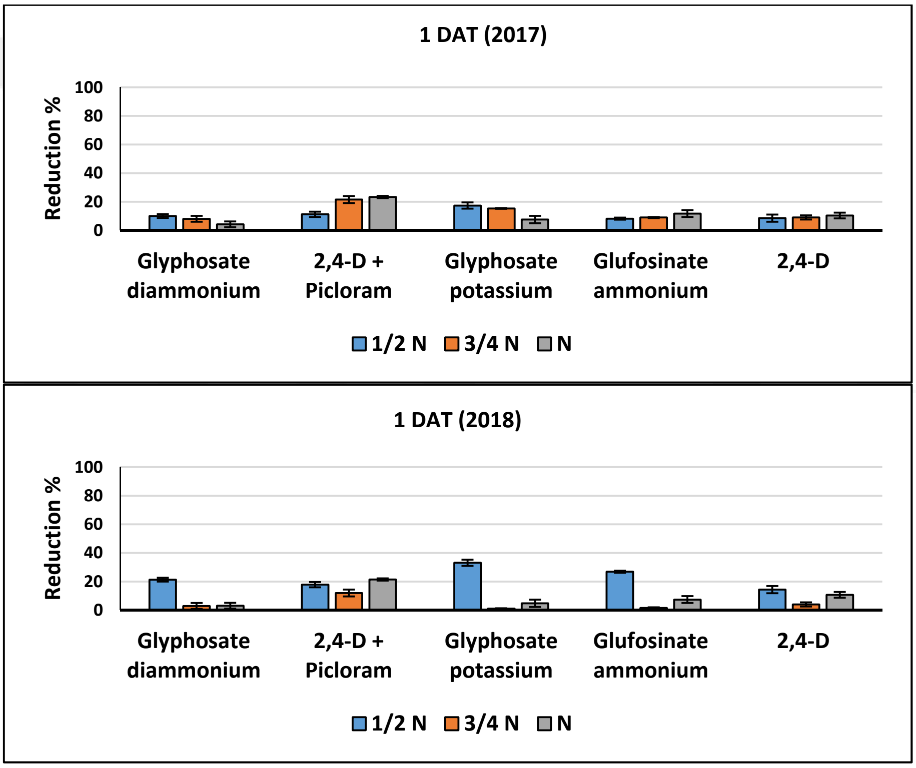


Figure 4.30. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D+picloram) at the 1st day after treatment during two-year experiment (2017 and 2018).

In 2017, plants started showing a recognizable growth reduction with recommended, two-third and half doses of premix herbicide (41.46%, 31.98% and 30.14%,) and glyphosate potassium salt (25.14%, 25.57% and 30.19%) on the third day of the experiment. In the 2018 experiment, efficacy of glyphosate potassium was disappeared, especially at recommended and two-third doses. However, 2,4-D + picloram was the only herbicide showed visible reduction in dwarf mesquite growth (Fig. 4.31).

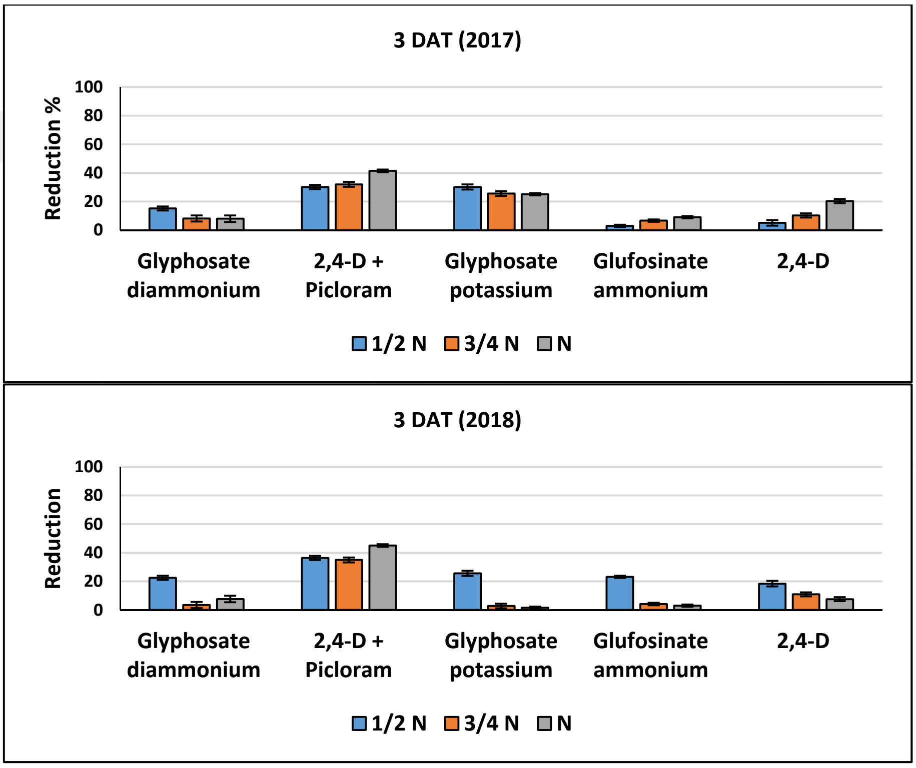


Figure 4.31. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D+picloram) at the 3rd day after treatment during two-year experiment (2017 and 2018).

In the fifth day of the first experiment conducted in 2017, the percentage reduction in plant growth caused by glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine was 12.98%, 75.06%, 3.98%, 22.27% and 30.05% at their recommended doses; 12.23%, 70.54%, 5.12%, 17% and 21.45% at their two-third doses; and 13.98%, 65.14%, 7.39%, 15.27% and 20.54% at their half doses, respectively. While in the fifth day of the 2018 experiment, the percentage reduction in *P. farcta* growth provided by glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine was 23.44%, 74.83%, 4.1%, 15.23%, 29.13% at recommended doses; 12.58%, 74.83%, 1.32%, 19.86% and 21.19% at two-third doses; and 19.2%, 69.53%, 15.89%, 24.5% and 23.97% at half doses, respectively. It has been shown that premix herbicide was the only herbicide remarkably reduced growth of dwarf mesquite with its three doses dose on the fifth day of the experiment (Fig. 4.32).

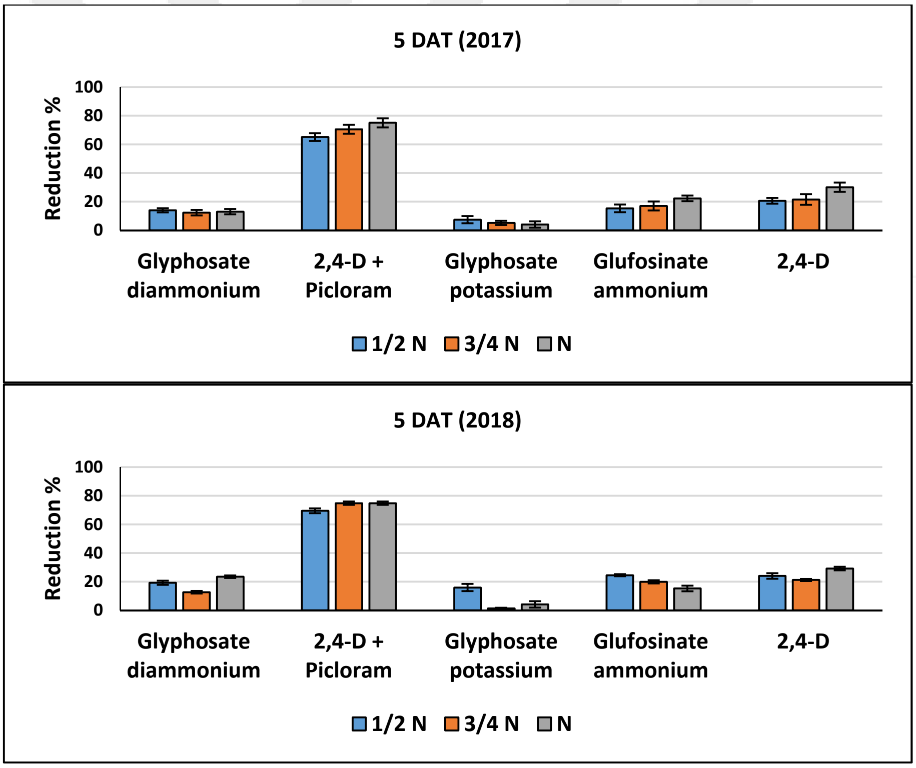


Figure 4.32. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D+picloram) at the 5th day after treatment during two-year experiment (2017 and 2018).

After one week of herbicide application in the first experiment, percentage reduction in plant growth provided by glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine at their half, two-third and recommended doses were (19.57%, 21.19% and 40.02%); (87.24%, 90.43% and 100%); (17.17%, 30.03% and 25.32%); (25.18%, 36.43% and 44.23%) and (33%, 34.47% and 35.1%), respectively. in the second experiment, glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine provided (22.21%, 28.49% and 46.13%); (94.08%, 97.63% and 100%); (15.35%, 33.7% and 27.78%); (27.78%, 41.51% and 24.58%) and (34.05%, 28.96% and 36.89%) at their half dose, two-third dose and recommended doses, respectively. For the two experiments (2017/18), premix herbicides achieved greater effect on dwarf mesquite growth with no difference ($P>0.05$) between three doses. All other herbicides caused less than 50 percent of mesquite shoot growth relative to the untreated control (Fig. 4.33).

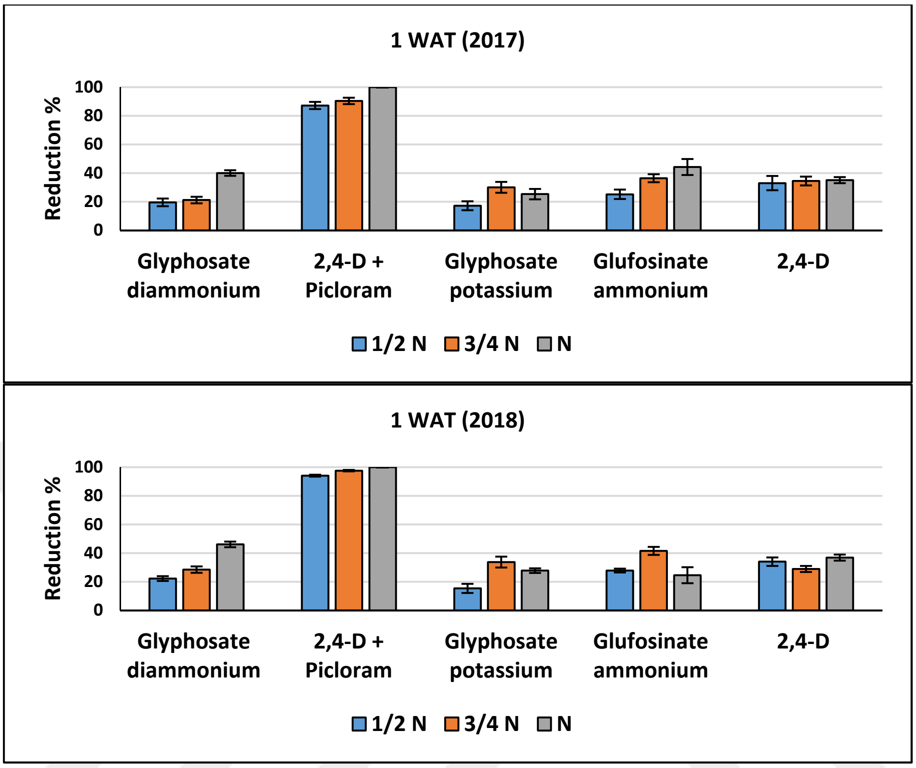


Figure 4.33. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D+picloram) at the 1st week after treatment during two-year experiment (2017 and 2018).

In the second week of the 2017 experiment, 2,4-D plus picloram was the most effective herbicide on mesquite growth at its three doses (100%), followed by glyphosate diammonium (90.34%), glyphosate potassium (90.32%), glufosinate (73.18%) and 2,4-D amine (70.03%) at their recommended doses. while application of reduced doses of other herbicides showed less than 50% reduction in shoot growth. In 2018, the reduced doses of the 2,4-D+picloram caused slightly more reduction in dwarf mesquite shoot growth compared to the recommended dose. Except for the recommended doses of glufosinate ammonium (97.03%) and glyphosate diammonium (94.07%), the other herbicide treatments appeared to be less effective against dwarf mesquite (Fig. 4.34).

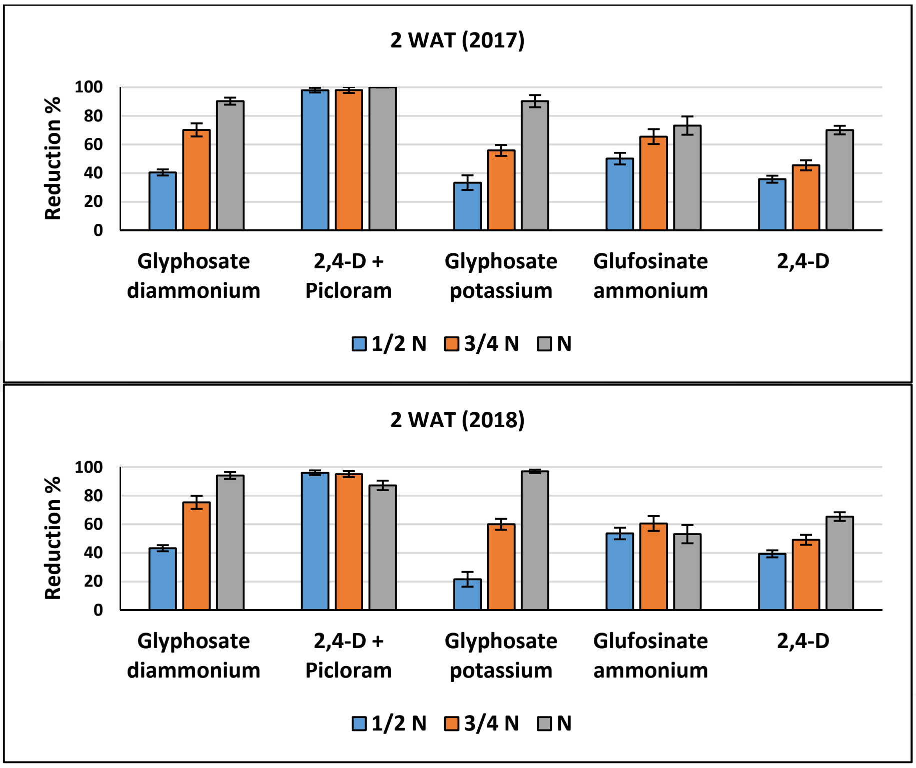


Figure 4.34. Percentage reduction in shoot height of dwarf mesquite [Prosopis farcta (Banks & Sol.) F.J. Mac.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D+picloram) at the 2^{nd} week after treatment during two-year experiment (2017 and 2018).

In the 3^{rd} week of the 2017 experiment, percentage reduction in shoot growth of *P. farcta* treated with glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine in their half dose, tow-third dose and recommended dose was (70.34%, 92.03% and 100%); (100%, 100% and 100%); (34.04%, 68.375 and 100%); (77.82%, 80.83% and 83.47%) and (48.07%, 69.87% and 72.39%), respectively. In the 2018 experiment, application of glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine resulted in (69.12%, 90.29% and 98.23%); (100%, 92.94% and 100%); (17.52%, 76.18% and 100%); (86.76%, 84.56% and 77.94%) and (41.78%, 67.36% and 70.89%) reduction in plant growth, respectively (Fig. 4.35).

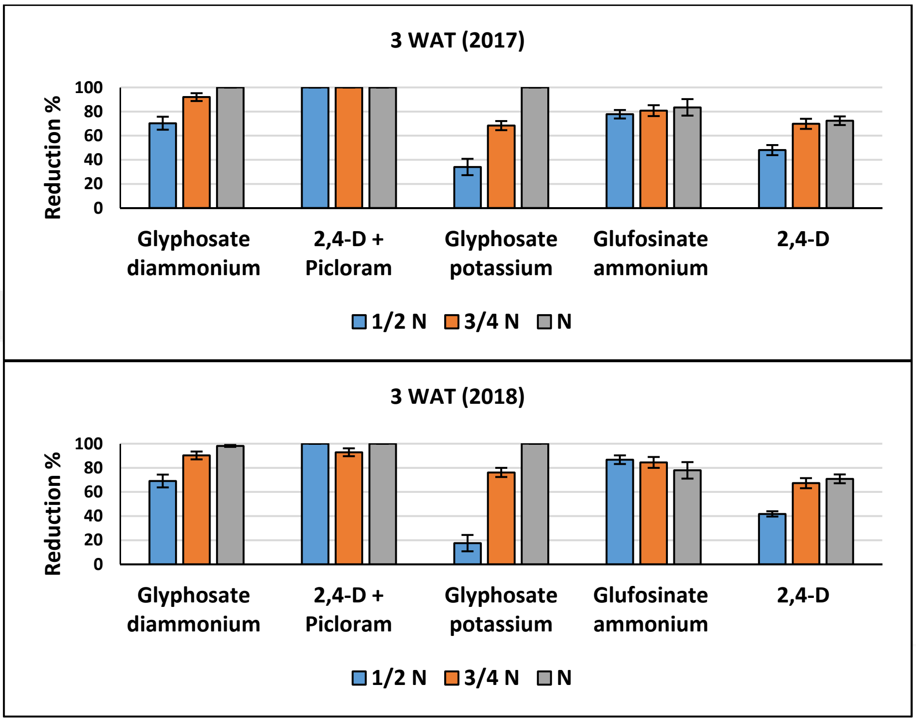


Figure 4.35. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 3rd week after treatment during two-year experiment (2017 and 2018).

In the fourth week of the first experiment (2017), glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine provided (80.03%, 97.34% and 100%); (100%, 100% and 100%); (10.43%, 80.43% and 98.53%); (80.34%, 98.54% and 90.64%) and (45.45%, 82.27% and 94.3%) reduction in plant growth at their half, two-third, and recommended doses, respectively. In the second experiment (2018), percentage reduction in plant growth caused by application of glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine at their ½ N, 2/3 N and N dose was (76.05%, 95.64% and 100%); (100%, 100% and 100%); (15.11%, 84.87% and 100%); (96.37%, 92.01% and 84.03%) and (59.37%, 89.11% and 92.01%), respectively (Fig. 4.36).

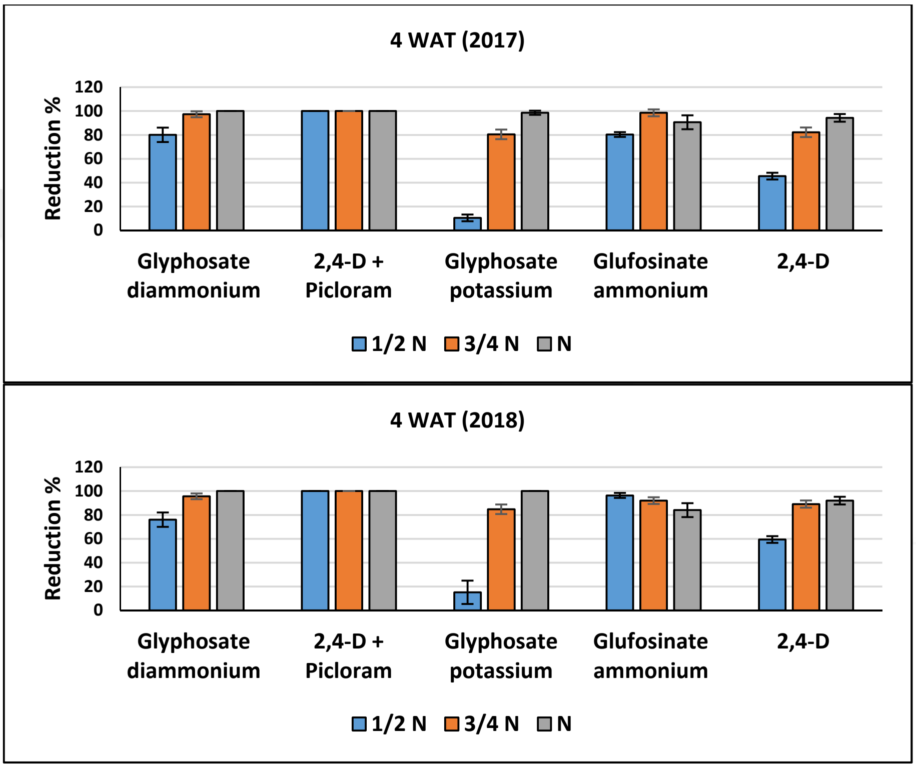


Figure 4.36. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 4th week after treatment during two-year experiment (2017 and 2018).

At the end of the 2017 experiment, (85.03%, 91.38% and 100%); (100%, 100% and 100%); (17.46%, 89.38% and 100%); (84.83%, 100% and 100%) and (100%, 100% and 100%) reduction in growth of dwarf mesquite was caused application of glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine at their ½ N, 2/3 N and N doses, respectively. In the 2018 experiment, glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine provided (81.77%, 94.84% and 100%); (100%, 100% and 100%); (36.59%, 91.67% and 100%); (95.64%90.88% and 85.73%) and (100%, 100% and 100%) reduction in dwarf mesquite growth, respectively (Fig. 37).

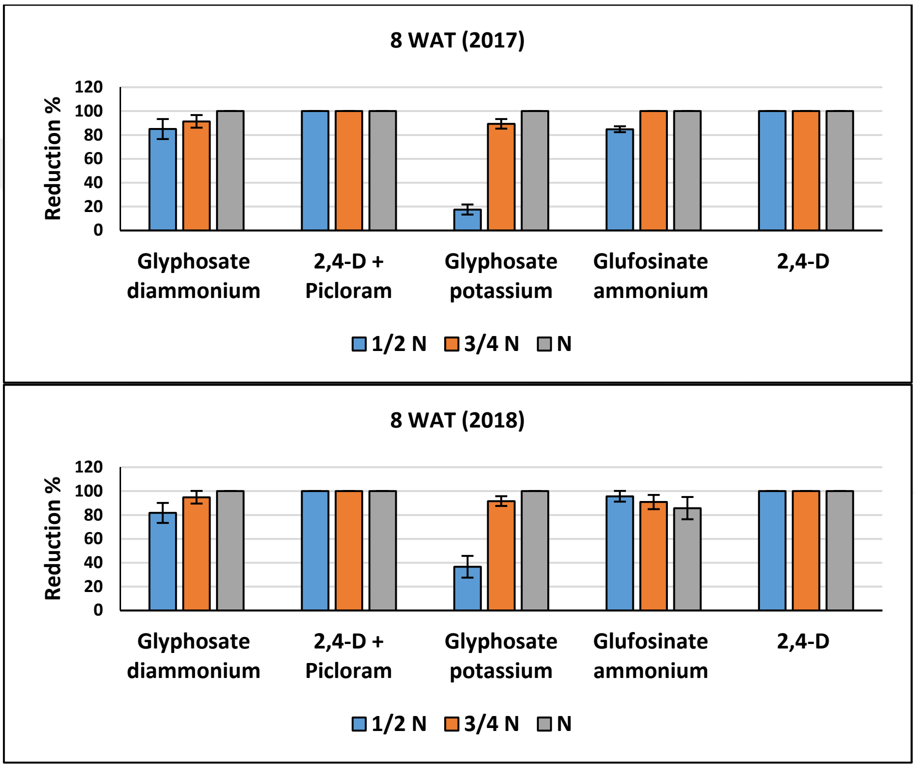


Figure 4.37. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 8th week after treatment during two-year experiment (2017 and 2018).

4.3.3. Effect of Herbicides on the Biomass of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.]

4.3.3.1. The Effect on the Fresh Weight

In 2017, the highest reduction in mesquite fresh weight was achieved by 2,4-D plus picloram at its half, two-third and recommended doses (95.05%, 97% and 98.9%), followed by glyphosate diammonium (92.18%, 98.23% and 98.88%), glyphosate potassium (54.96%, 97.02 and 98%); 2,4-D amine (83.34%, 95.09% and 96.38%) and glufosinate ammonium (90.59%, 9384% and 96.03%). In the second experiment (2018), the least fresh weight was obtained from plants treated with the 2,4-D+picloram at its ½ N (2838 g a.i. ha^{-1}), 2/3 N (3784 g a.i. ha^{-1}) and N (5677 g a.i. ha^{-1}) doses (97.84%, 97.94% and 97.56% reduction), followed by glyphosate diammonium glufosinate ammonium (95.46%, 97.18% and 97.4% reduction), glufosinate ammonium (97.89%, 97.56% 97.4%) and 2,4-D amine (80.93%, 96.85% and 97.35%). Ganie et al., (2017), suggested that the glyphosate absorption and translocation has been improved at higher temperatures. However, treatment with glyphosate potassium was only effective at the recommended and two-third doses (96.62% and 97.96%) where the half dose found to be less effective (58.36%) comparing to half doses of other herbicides. For the two years, except half dose of glyphosate potassium, there were no differences among the three doses of all herbicides. Similarly, statistically there were no differences among the herbicide treatments throughout the two-year experiment. Akkuzu, (2012) stated that glyphosate and 2,4-D caused about 65% reduction in the fresh weight of the dwarf mesquite when applied at higher doses. However, in our study, the effect was more significant and the reason is that we have applied the herbicide on the dwarf mesquite at early growth stage (Fig. 4.38).

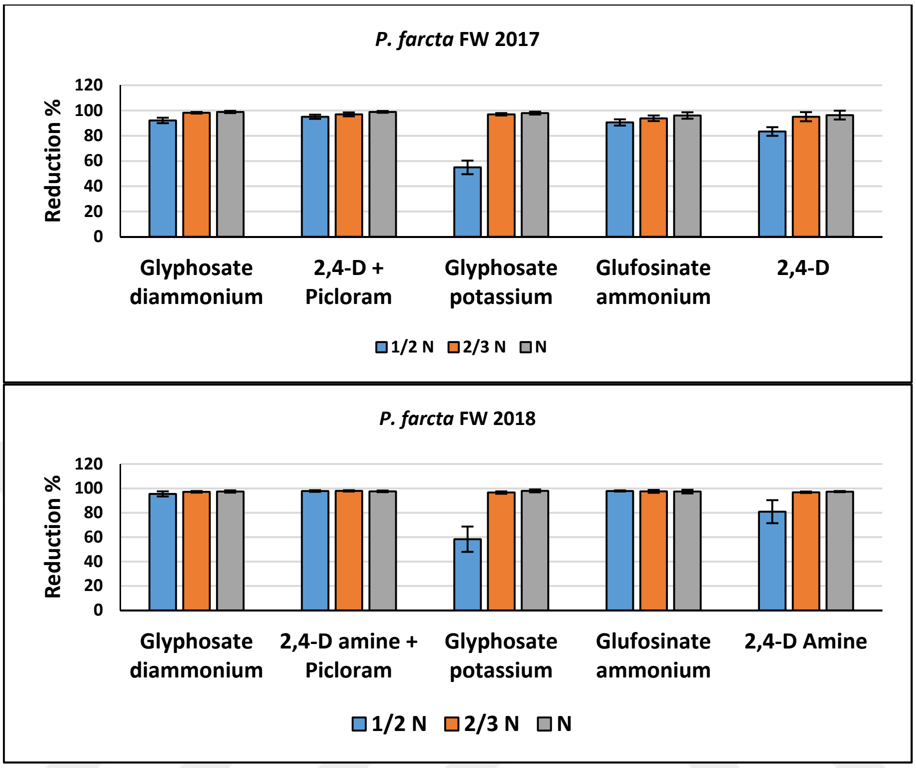


Figure 4.38. Effect of five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on the fresh weight (FW) of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] during two-year experiment (2017 and 2018).

4.3.3.2. The Effect on the Dry Weight

In the 2017 experiment, all herbicides significantly affected *P. farcta* dry weight with all tested doses. In this experiment, (90.47%, 93.9% and 96.04%); (96.02%, 96.04% and 98.48%); (63.31%, 94.29% and 96.37%); (95.48%, 95.89% and 97%) and (80.01%, 91.74% and 96.16%) percentage reduction in dry weight was found as a result of application of glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine and their ½ N, 2/3 N and N doses, respectively. In the 2018 experiment, the five herbicides (glyphosate diammonium, 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium and 2,4-D amine) caused (94.74%, 95.46% and 95.75%); (96.38%, 96.38% and 96.31%); (59.51%, 96.04% and 96.19%); (96.86%, 96.33% and 96.86%) and (81.74%, 95.12% and 95.94%) reduction in plant dry weight, respectively. Akkuzu (2012) was reported that glyphosate potassium and 2,4-D amine were significantly reduced the dry weight of *P. farcta*. In another research, Qasem (2007) reported moderate efficacy of 2,4-D amine on the dry weight of dwarf mesquite. Our study result confirms that has been stated in the previous studies (Fig. 4.39).

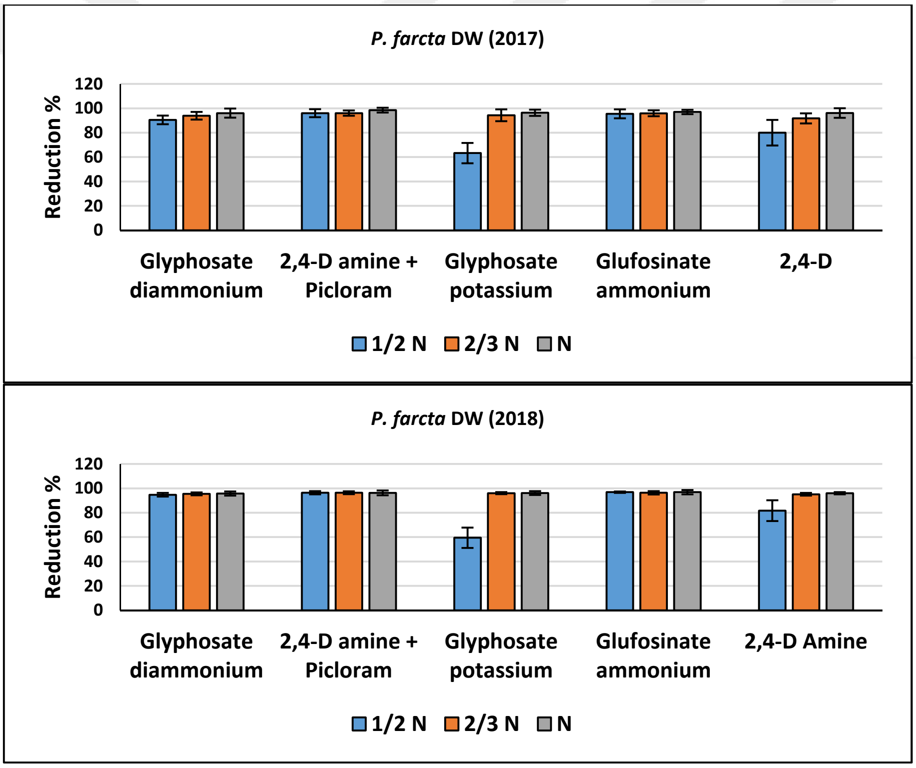


Figure 4.39. Effect of five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on the dry weight (DW) of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.] during two-year experiment (2017 and 2018).

4.4. Chemical Control of Common Mesquite (*P. juliflora*) under Greenhouse Conditions

4.4.1. Percentage Control of Common Mesquite [*Prosopis juliflora* (Sw.) DC.]

4.4.1.1. Effect of Glyphosate Diammonium

Glyphosate diammonium has shown its effect on common mesquite seedlings only one week after application under greenhouse conditions. In the first experiment, the control percentage provided by this herbicide at its recommended dose (3392 g a.i ha^{-1}) was 73.12%, 90.43%, 92.89%, 100% and 100% in the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 8^{th} WAT, respectively. Control provided at the two-third dose (2261 g a.i ha^{-1}) was 70.33%, 85.34%, 92.65%, 100% and 100% in the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 8^{th} week after herbicide application, respectively. However, at its half dose (1696 g a.i ha^{-1}), the glyphosate diammonium caused percentage control of 23.33%, 40.23%, 45.34%, 80.43% and 100% in the first, second, third, fourth and eighth week after treatment (WAT), respectively. In the second experiment, glyphosate diammonium achieved 70.83%, 94.16%, 95.83%, 100% and 100% at recommended dose; 74.66%, 89.33%, 90.33%, 97.5% and 100% at two-third dose; and 15.83%, 35.66%, 41.5%, 84.16% and 83.33% in the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 8^{th} WAT, respectively. Neal et al. (1985) was suggested that the glyphosate absorption and translocation was significantly linked to the growth stage of the woody plant. In the same way, common mesquite was found to be more sensitive to glyphosate-based herbicides in the early developmental growth stages (Fig. 4.40).

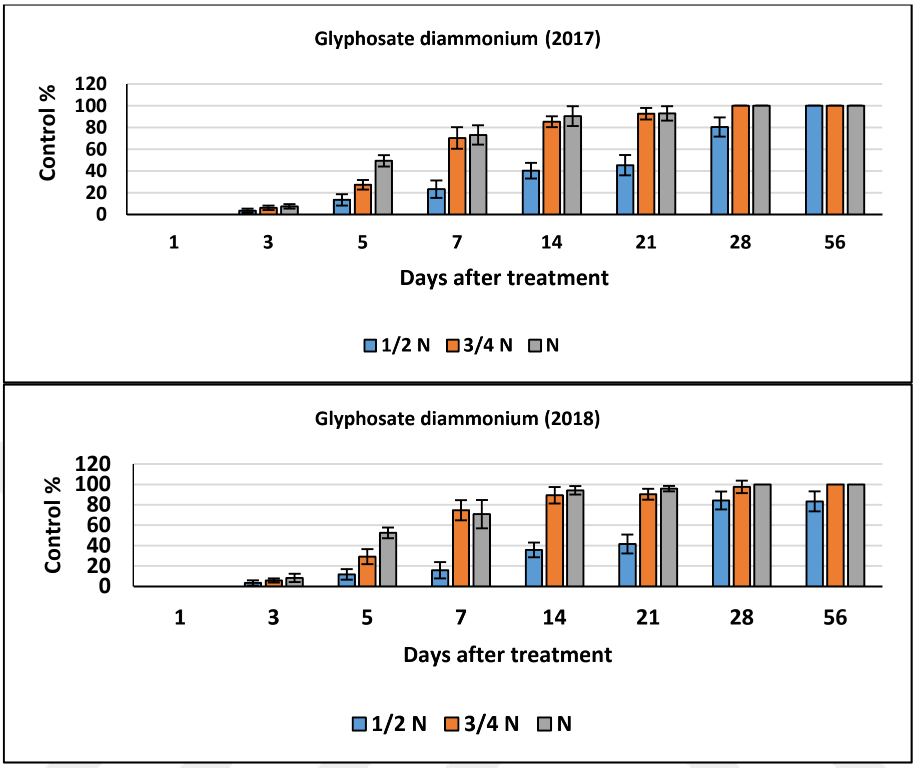


Figure 4.40. Percentage control of common mesquite [*Prosopis juliflora* (Sw) DC.] achieved by 424 g/l glyphosate di-ammonium salt applied in three doses (1/2 N, 2/3 N and N) during two-year greenhouse experiment (2017 and 2018).

4.4.1.2. Effect of Glyphosate Potassium

In the first experiment conducted in 2017, glyphosate potassium was found to be more effective against *P. juliflora*, providing 95.35%, 98.35%, 99.46%, 100%and 100% mesquite control with its recommended dose (3969 g a.i ha^{-1}) in the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 8^{th} week after its application, respectively. The percentage control achieved when applied at two-third dose (2646 g a.i ha^{-1}) was 65.76%, 90%, 85.36%, 100% and 100% in the first, second, third, fourth and eighth week after treatment, respectively. Application at half dose (1984 g a.i ha^{-1}) resulted in 46.78%, 70.65%, 70.36, 100% and 100% control in the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 8^{th} week of the experiment, respectively. In the second-year greenhouse study, 94.5%, 100%, 100%, 100% and 100% of mesquite control was observed during the first, second, third, fourth and eighth WAT, respectively when glyphosate potassium was applied at the label dose. However, 61.5%, 97.5%, 100%, 100%, 100% and 100% mesquite control was recorded at two-third dose; and 41.66%, 56.66%, 6583%, 90.83% and 66.66% at half dose during the 1st, 2nd, 3rd, 4th and 8th WAT, respectively (Fig. 4.41).

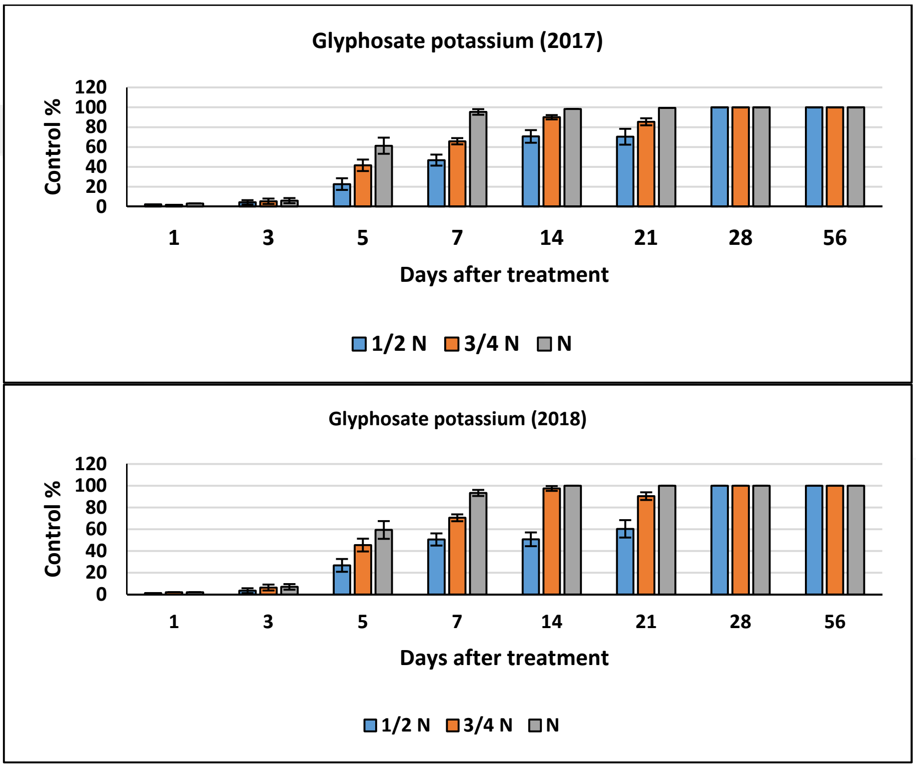


Figure 4.41. Percentage control of common mesquite [*Prosopis juliflora* (Sw) DC.] achieved by 441 g/l glyphosate potassium applied in three doses (1/2 N, 2/3 N and N) during two-year greenhouse experiment (2017 and 2018).

4.4.1.3. Effect of Glufosinate Ammonium

In the first-year greenhouse experiment, the percentage control of common mesquite provided by glufosinate ammonium at recommended dose (1500 g a.i ha^{-1}), relative to the untreated control was 90.23%, 90.43%, 97%, 100% and 100%

during 1, 2, 3, 4 and 8 WAT, relatively. When contact herbicide, glufosinate was applied at two-thirds dose (1000 g a.i ha^{-1}), the herbicide was found to provide 86.5%, 83.65%, 89.54%, 100% and 90.43% control during the 1, 2, 3, 4 and 8 WAT, and 70%, 40.53%, 50.43%, 30.05% and 25.12% control at half dose (750 g a.i ha^{-1}) during the 1,2,3,4 and 8 WAT, respectively. In the second experiment, 88.16%, 92.83%, 95.33%, 100% and 100% mesquite control was observed during the 1st, 2nd, 3rd, 4th and 8th WAT when glufosinate was applied at recommended dose, respectively. However, application of glufosinate at two-third dose and half dose resulted in 86.5%, 81.66%, 86.66%, 84.16% and 84.16; and 61.66%, 50%, 57.5%, 21.66%, 12.5% mesquite control during the 1, 2, 3, 4 and 8 WAT, respectively (Fig. 4.42).

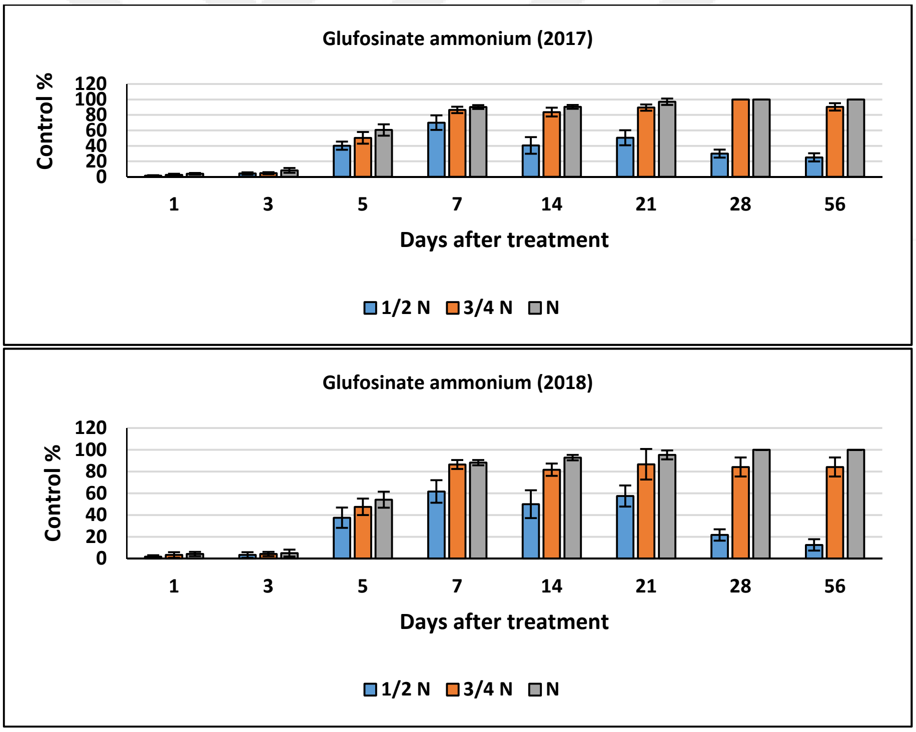


Figure 4.42. Percentage control of common mesquite [*Prosopis juliflora* (Sw) DC.] achieved by 200 g/l glufosinate ammonium salt applied in three doses (1/2 N, 2/3 N and N) during two-year greenhouse experiment (2017 and 2018).

4.4.1.4. Effect of 2,4-D Amine

In the two experiments, it was observed that common mesquite (*P. juliflora*) has survived after being exposed to reduced doses of growth regulator, 2,4-D amine. In 2017, the herbicide was only effective after two weeks of its application, where 70.83, 80.34, 94.34 and 81.43 percent control was provided during the 2, 3, 4 and 8 WAT, at the recommended dose (1500 g a.i ha^{-1}). Similarly, in the 2018 experiment, the biological activity of this herbicides was considerably low and invisible, relative to the untreated control seedlings. In all experiments, common mesquite seedlings treated by 2,4-D was effectively controlled until the eighth week after treatment and then gradual decline in its herbicidal activity was observed by the end of the experiment (Fig. 4.43).

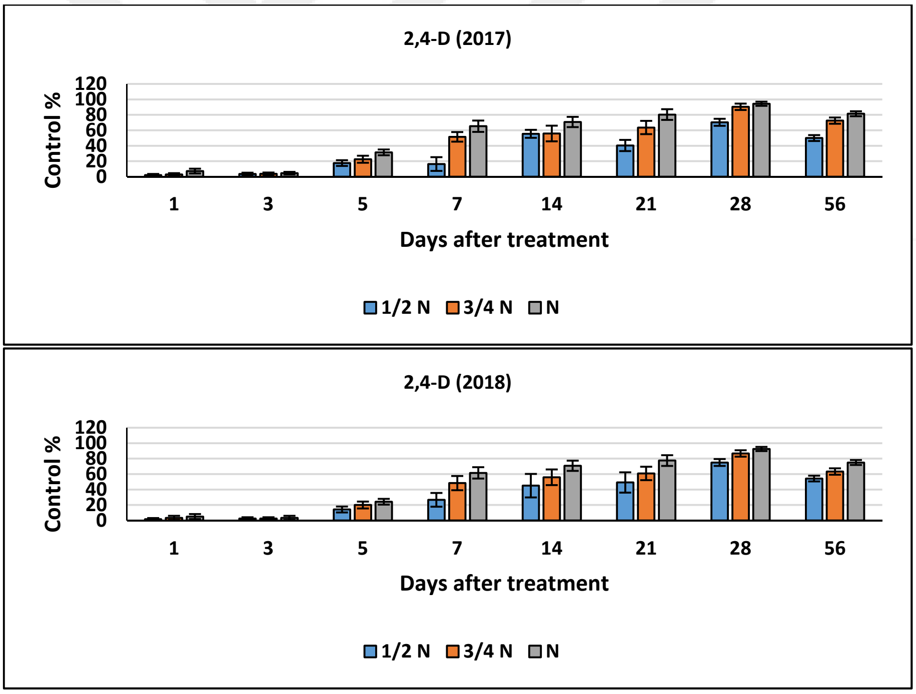


Figure 4.43. Percentage control of common mesquite [*Prosopis juliflora* (Sw) DC.] achieved by 500 g/l 2,4-D amine salt applied in three doses (1/2 N, 2/3 N and N) during two-year greenhouse experiment (2017 and 2018).

4.4.1.5. Effect of 2,4-D Tri-isopropylamine + Picloram

Application of 2,4-D tri-isopropylamine + picloram-based premix herbicide was found to cause the highest control against common mesquite under greenhouse conditions. In the 2017 experiment, percentage control obtained from recommended dose (5677 g a.i ha^{-1}) treatment was 96.43%, 100%, 100%, 100% and 100% during the 1, 2, 3, 4 and 8 WAT, respectively. Likewise, 2,4-D +picloram provided 93.12%, 100%, 100%, 100% and 100% mesquite control at two-third dose (3784 g a.i ha^{-1}); and 90.05%, 100%, 100%, 100% and 100% control at half dose (2838 g a.i ha^{-1}) during 7, 14, 21, 28 and 56 days after treatment (DAT), respectively. In 2018, the herbicide showed the same effectiveness against common mesquite, where the seedlings were successfully controlled the plant seedlings only seven days after the treatment and there was no regrowth observed. This indicates that this herbicide was effective enough to prevent plant recovery. Jacoby et al., (1981) reported that aerial application of 3,6-Dichlorocolinic acid provided excellent control of honey mesquite (*P. juliflora* var. *glandulosa*) compared to 2,4,5-T and 2,4,5-T plus picloram. Sosebee (1974), found that shredding and spraying of 2,4,5-T plus picloram was effectively controlled mesquite (*Prosopis juliflora*) (Fig. 4.44).

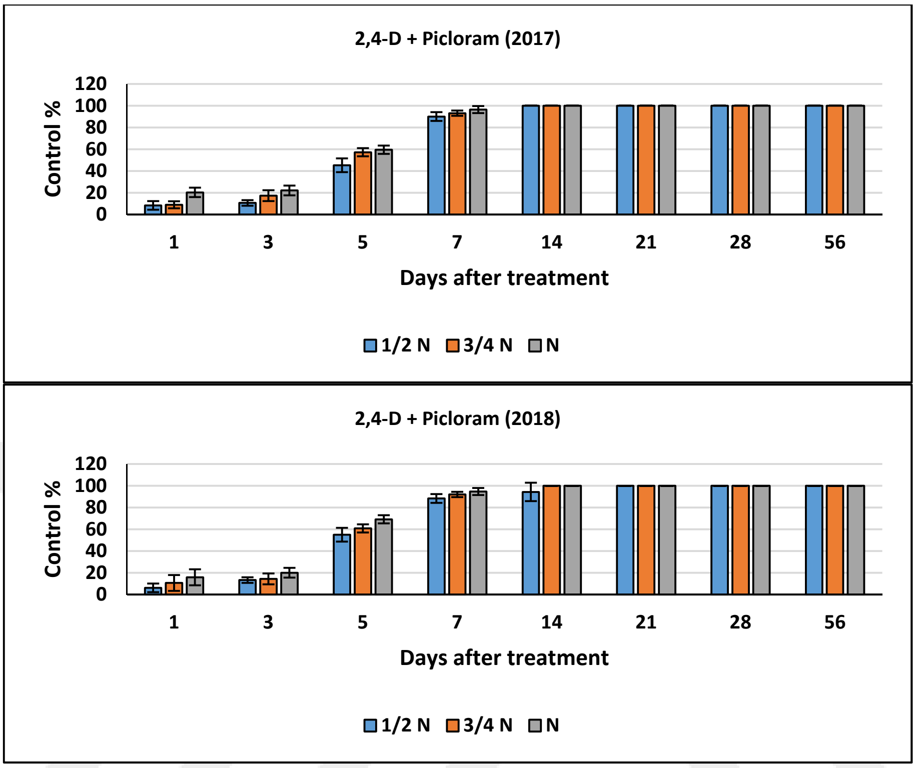


Figure 4.44. Percentage control of common mesquite [*Prosopis juliflora* (Sw) DC.] achieved by 451.4 g/l 2,4-D tri-isopropylamine + 116.3 g/l picloram applied in three doses (1/2 N, 2/3 N and N) during two-year greenhouse experiment (2017 and 2018).

4.4.1.6. The Comparative Control of Common Mesquite (*P. juliflora*)

In the first day of the first experiment, all herbicide treatments showed almost no effect on *P. juliflora* relative to the untreated control. In addition, there was no difference (P>0.05) between herbicides doses, indicating slow uptake and/or translocation of all herbicides. The same was found in the second greenhouse experiment, when common mesquite was found to develop no recognizable symptoms as a response to herbicide application (Fig. 4.45).

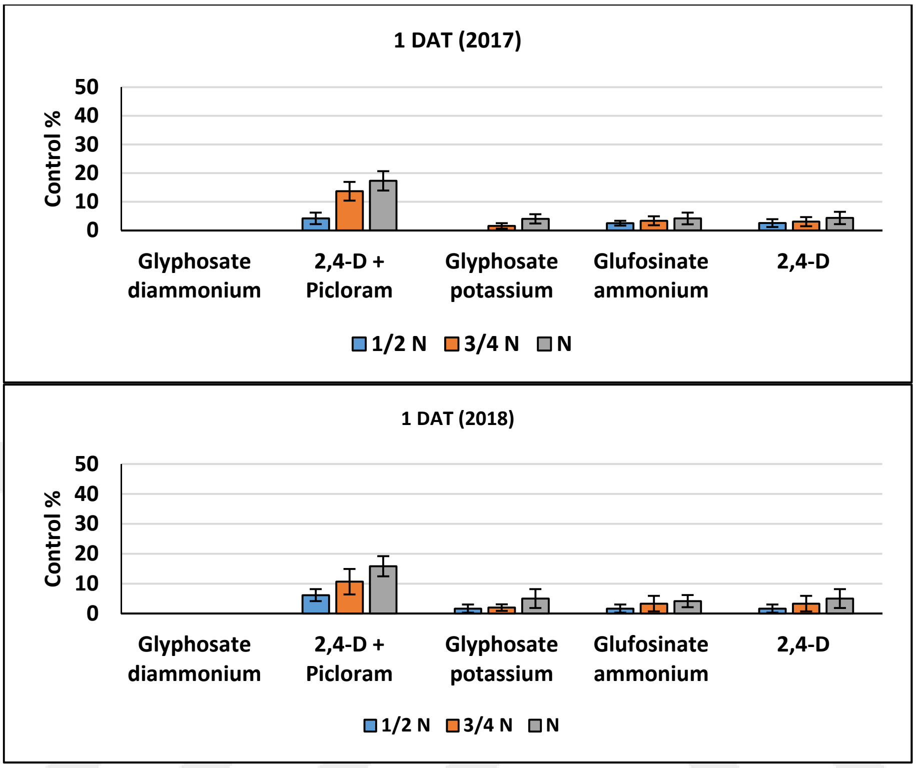


Figure 4.45. Percentage effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.] under greenhouse conditions at the 1st day after herbicide application during two-year experiment (2017 and 2018).

For the two-year experiments, except for 2,4-D triisopropylamine + picloram, the percent control provided by other herbicides was invisible on *P. juliflora* seedlings until three days after treatments. Even the premix herbicide provided only 15.99%, 17.44% and 21.05% mesquite control in the first experiment and 13.33%, 14.33% and 20% control in the second experiment at its ½ N (2838 g a.i ha^{-1}), 2/3 N (3784 g a.i ha^{-1}) and N (5677 g a.i ha^{-1}) rates, respectively (Fig. 4.46).

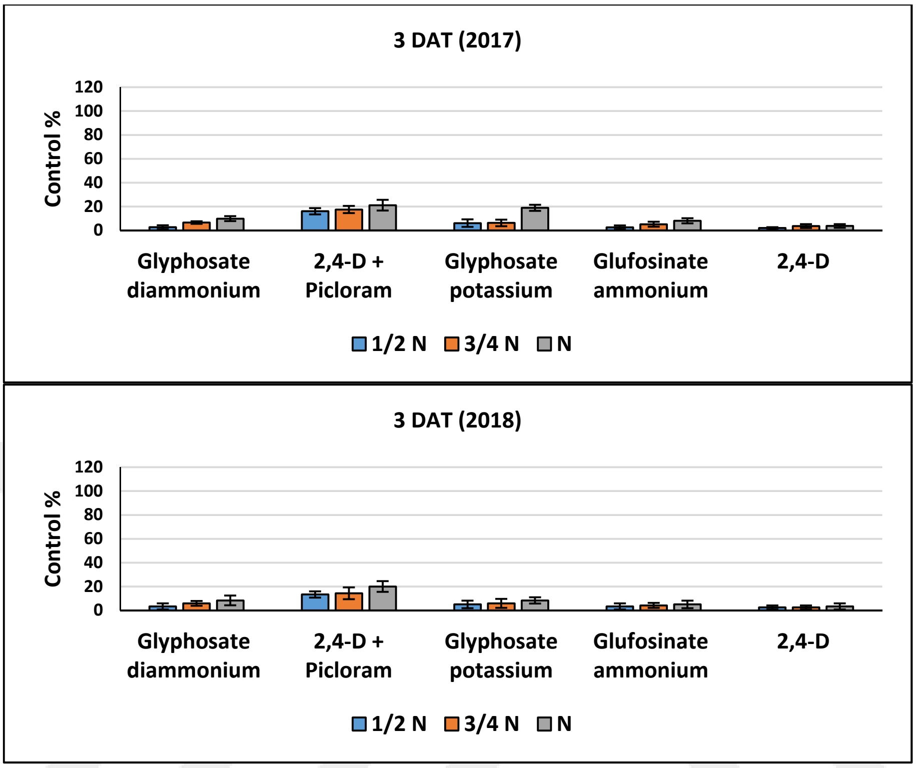


Figure 4.46. Percentage effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.] under greenhouse conditions at the 3rd day after herbicide treatment during two-year experiment (2017 and 2018).

On the fifth day after treatment (DAT) of the 2017 experiment, more than 50% control was obtained with some herbicide treatments. For instance, 2,4-D + picloram provided 50.56%, 55.54% and 72.44% mesquite control at its ½ N, 2/3 N and N dose; glyphosate potassium caused 54.33% mesquite control at its recommended dose (3969 g a.i ha^{-1}); and glufosinate ammonium achieved 50.33% and 55.77% mesquite control at its 2/3 N (1000 g a.i ha^{-1}) and N (1500 g a.i ha^{-1}) doses respectively. In 2018 experiment, no effective control was found, where relatively the same herbicide efficacy was found in all herbicide treatments. However, in this experiment, 52.5% control was provided by glyphosate diammonium at its recommended dose (3392 g a.i ha^{-1}); 55%, 60.83% and 69.16% control provided by 2,4-D plus picloram at ½ N, 2/3 N and N rates; 53.33% control caused by glyphosate potassium at N rate; and 54.16% mesquite control was recorded at the recommended dose of glufosinate ammonium. . Feldman and Galvan, (1972) reported that the mixture of picloram and diesel or kerosene to be effective on *P. ruscifolia* and provided 83% control. Although none of the 2,4-D amine rates showed herbicidal activity on common mesquite, combination of 2,4-D and picloram provided greatest control, indicating that addition of 2,4-D was incredibly increased the effectiveness of picloram by transforming it into an extremely toxic to common mesquite (Fig. 4.47).

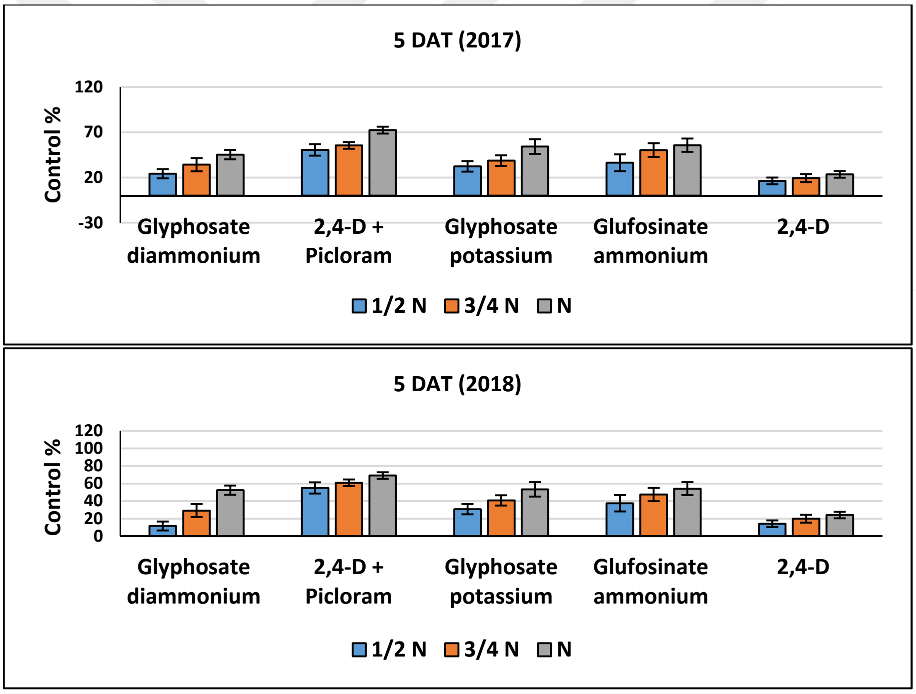


Figure 4.47. Percentage effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.] under greenhouse conditions at the 5th day after herbicide application during two-year experiment (2017 and 2018).

Within a week after spraying, nearly all herbicides seemed more effective and successfully controlled *P. juliflora* during the two experiments. In the first experiment, 2,4-D plus picloram provided 90.33%, 92% and 96.33% control, showing the highest effect on the above-ground part of common mesquite; followed glyphosate potassium at its recommended dose (94.5%); glufosinate ammonium at two-third and label recommended dose (87.5% and 85.23%); glyphosate potassium (38.41, 63.82 and 95%) at its ½ N, 2/3 N and N rates; glyphosate diammonium (71.45%, 72.54 and 72.66%), where the 2,4-D was hah showed no effect. In the second experiment, the premix herbicide remained the most effective herbicide against *P. juliflora*, causing 94.66%, 92% and 88.33% control with its recommended, two-third and half dose, respectively. However, the recommended dose of glyphosate potassium was found to deliver the second highest mesquite control after that caused by 2,4-D + picloram treatment (Fig. 4.48).

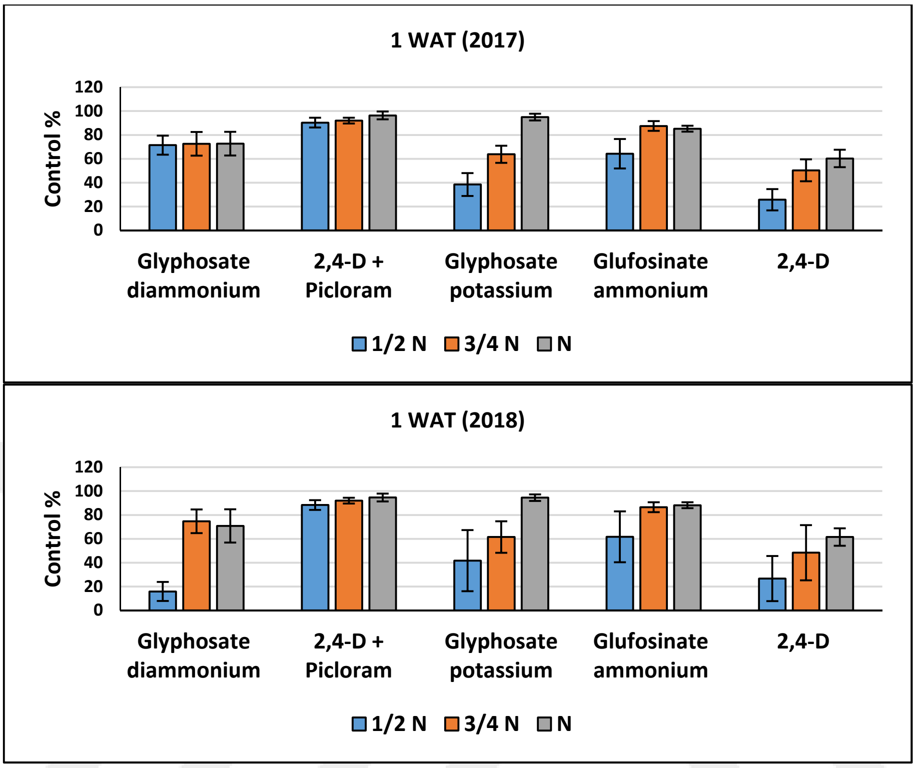


Figure 4.48. Percentage effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied at three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.] under greenhouse conditions during the 1st week after herbicide application during two-year experiment (2017 and 2018).

Application of glyphosate-based herbicides resulted in clear stunting and growth distortion of mesquite plants. However, necrosis, necrotic spots, stunting and leaf malformation was found in mesquite shoots exposed to glufosinate-ammonium. Furthermore, symptoms such as necrosis, stem malformation, tem dieback, leaf crinkling, leaf curling, and vein discoloration were obviously seen on *P. juliflora* seedlings treated by 2,4-D amine herbicides, all rates of 2,4-D + picloram caused stunting, defoliation and accelerated severe death of mesquite seedlings, showing the typical symptoms of synthetic auxins on younger plants (Fig. 4.49).

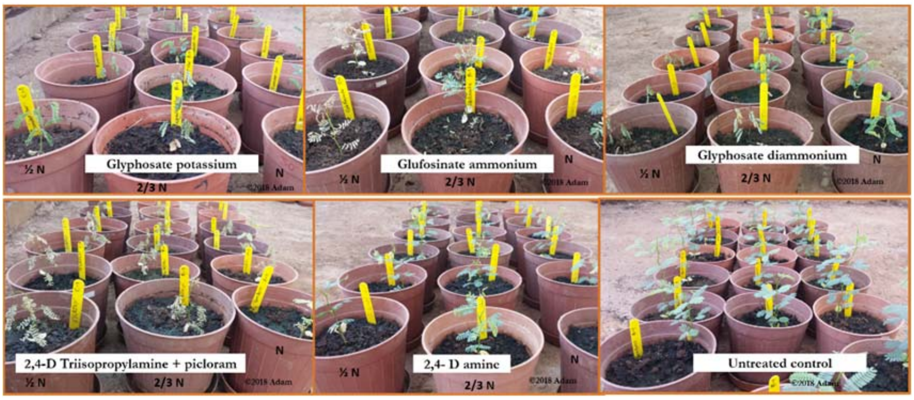


Figure 4.49. Percentage control provided by five herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied at three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.] during the 1 WAT for a two-year greenhouse experiment (2017 and 2018).

In the second week, all herbicides provided effective mesquite control during the two-year experiments with considerable variations among herbicides and doses applied. However, in the first experiment, 2,4-D tri-isopropylamine + picloram more successfully controlled mesquite, scoring 100% killing of *P. juliflora* seedlings in all doses. Additionally, there was no significant difference among the three doses of 2,4-D + picloram treatments in terms of percentage control achieved relative to untreated control pots. Interestingly, the two glyphosate formulations, glyphosate potassium and glyphosate diammonium caused significantly great mesquite control with their 2/3 N (96.05% and 92.11%) and N (100% and 95.33%) treatments, respectively. During the second year, except for the half dose of glyphosate diammonium, all tested doses of glyphosate-based formulations, glufosinate ammonium and 2,4-D + picloram provided high levels of mesquite control. Relatively different herbicide efficiency was observed in the second year, when glufosinate was appeared to cause high control levels at its half and two-third doses and consequently being the fourth effective herbicides after 2,4-D tri-isopropylamine, glyphosate potassium and glyphosate diammonium (Fig. 4.50).

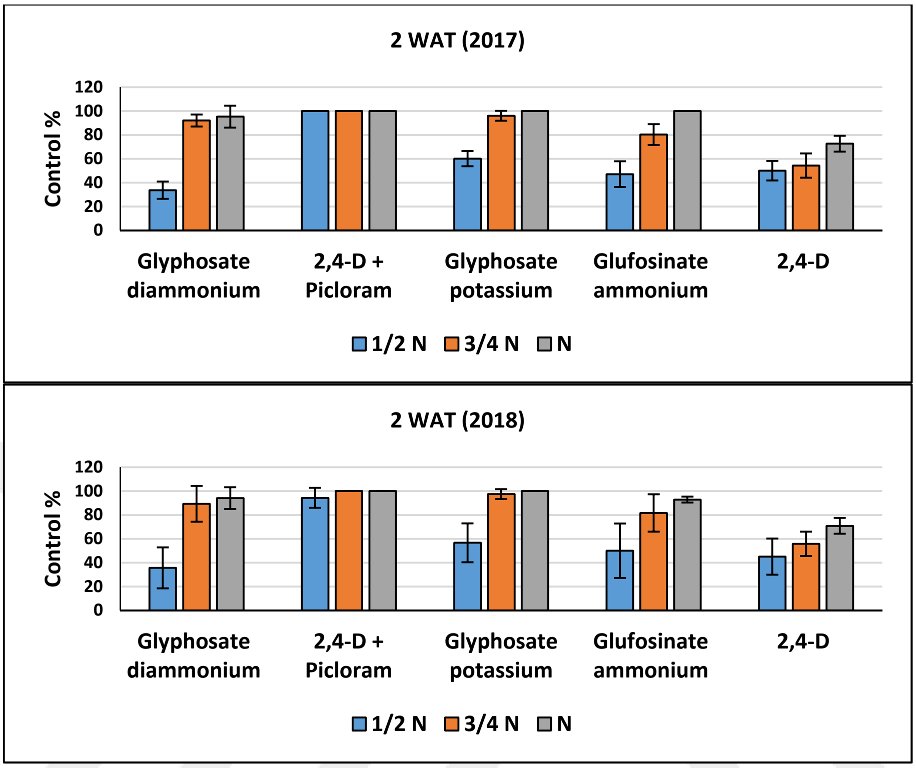


Figure 4.50. Percentage effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.] under greenhouse conditions at the 2nd week after herbicide application during two-year experiment (2017 and 2018).

During the second week of herbicide application only glyphosate potassium and 2,4-D triisopropylamine plus picloram showed significant control of common mesquite compared to other herbicide treatments (Fig. 4.51).

Figure 4.51. Effect of five herbicides (glyphosate potassium, untreated control, glufosinate ammonium, 2,4-D + picloram, 2,4-D amine and glyphosate diammonium) applied at three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.] in the 2 WAT for a two-year greenhouse experiment (2017 and 2018).

Common mesquite plants were kept under control as a result of herbicide applications until the end of the first 3 weeks of the experiment. In the first year, except the ½ N (2261 g a.i ha^{-1}) of glyphosate diammonium, all herbicide treatments provided mesquite control greater than 50%, making it difficult for mesquite seedling to take up enough water and resume growth. For the 2018 experiment, generally the effectiveness of herbicides against mesquite plants was the same as that obtained in the first year experiment (Fig. 4.52).

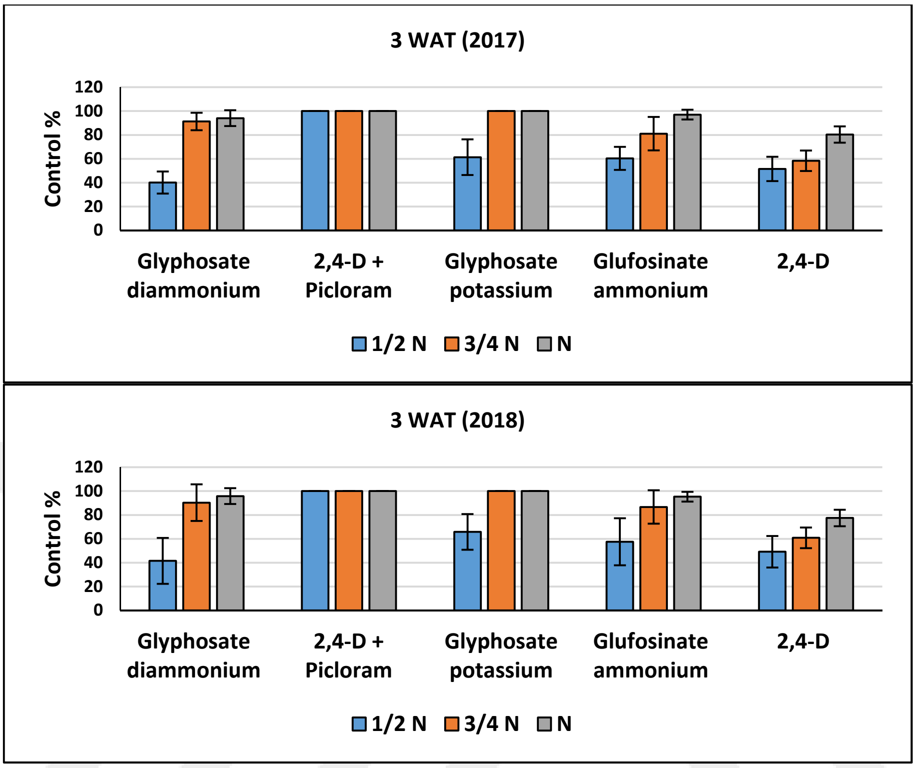


Figure 4.52. Percentage effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.] under greenhouse conditions at the 3rd week after herbicide application during two-year experiment (2017 and 2018).

Three weeks after treatment, beside 2,4-D plus picloram and glyphosate potassium treatments, glyphosate di-ammonium and glufosinate ammonium were also observed to provide an acceptable effect on *P. juliflora*'s seedlings. Whereas control caused by application of 2,4-D amine at three rates remained insignificant (Fig. 4.53).

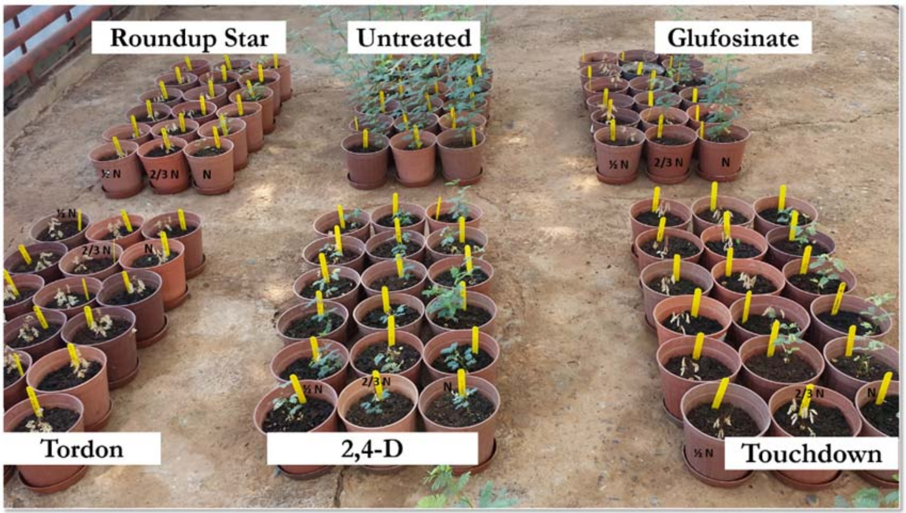


Figure 4.53. Percentage control caused by five herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied at three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.] in the 3 WAT for a two-year greenhouse experiment (2017 and 2018).

During the 2017 experiment, the percentages of mesquite control achieved by 2,4-D + picloram after one month of herbicide application were 100%, 100% and 100% at its N, 2/3 N and ½ N rates, respectively. The glyphosate potassium and glyphosate diammonium were observed to be the second and the third most effective herbicides, providing excellent control (100%) with their two-third and recommended doses and 93.44% and 85.05% with their half doses, respectively. However, the glufosinate aamonium provided 2.22, 79.77 and 100% control at the ½ N 2/3 N and N rates, respectively. The plants exposed to the 2,4-D amine treatment showed 94, 85.55 and 73.33% control for the N, 2/3 N and ½ N tares, recspectively. In 2018, the premix herbicide, 2,4-D+picloram continued to cause 100% control with the three doses and the glyphosate potassium and glyphosate diammonium were observed to be effective against common mesquite, causing (90.83, 100 and 100%) and (84.16, 97.5 and 100%) at their ½ N, 2/3 N and N doses, respectively. Whereas the glufosinate ammonium and 2,4-D amine delivered good control with their two-third and recommended doses. This may confirms Qasem, (2007) study, which reported a high efficacy against *P. farcta* (Fig. 4. 54).

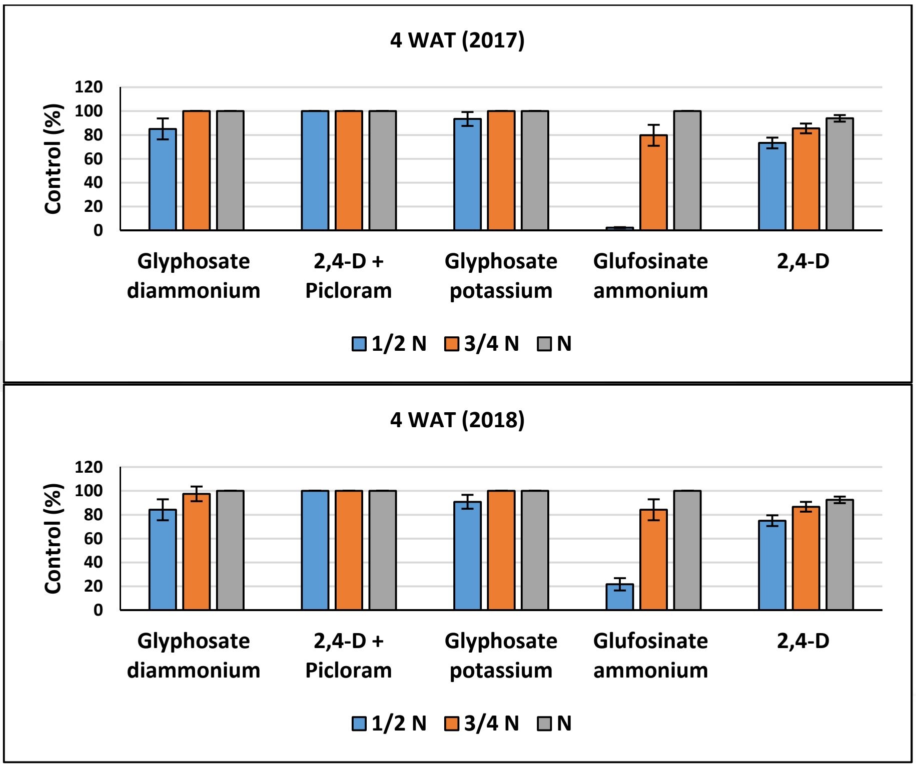


Figure 4.54. Percentage effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.] under greenhouse conditions at the 4th week after herbicide application during two-year experiment (2017 and 2018).

On the fourth week, leaves of common mesquite treated with picloram were turned yellow and eventually died. Glyphosate diammonium caused serious damage to the common mesquite shoot, with dried stems and leaves on majority of plants. However, 2,4-D amine treatment provided lower reduction in mesquite shoot compared to all other herbicides, but extreme stem malformation resulted in successful control relative to the untreated control (Fig. 4.55).

Figure 4.55. Effect of five herbicides (a= glyphosate potassium, b= untreated control, c= glufosinate ammonium, d= 2,4-D + picloram, e= 2,4-D amine and f= glyphosate diammonium) on common mesquite [*Prosopis juliflora* (Sw.) DC.] under greenhouse conditions at the 4th WAT during two-year experiment (2017 and 2018).

By the end of the first experiment, mesquite control was 100% in ½ N , 2/3 N and N doses of 2,4-D + picloram; 100%, 100% and 84% in N, ½ N and 2/3 N of glyphosate di-ammonium; 100%, 100% and 70% in N, 2/3 N and ½ N of glyphosate potassium; 100%, 83.44% and 15.04% for glufosinate ammonium and 77.03%, 62.33% and 55% in N, 2/3 N and ½ N of 2,4-D amine, respectively. As a result, 2,4-D amine was found to be the least effective herbicide against common mesquite. However, no significant differences were found among herbicides applied in the first and second experiments, indicating that herbicides were able to provide persistent and long-term of mesquite and eventually increased the efficiency of mesquite management efforts (Fig. 4.56).

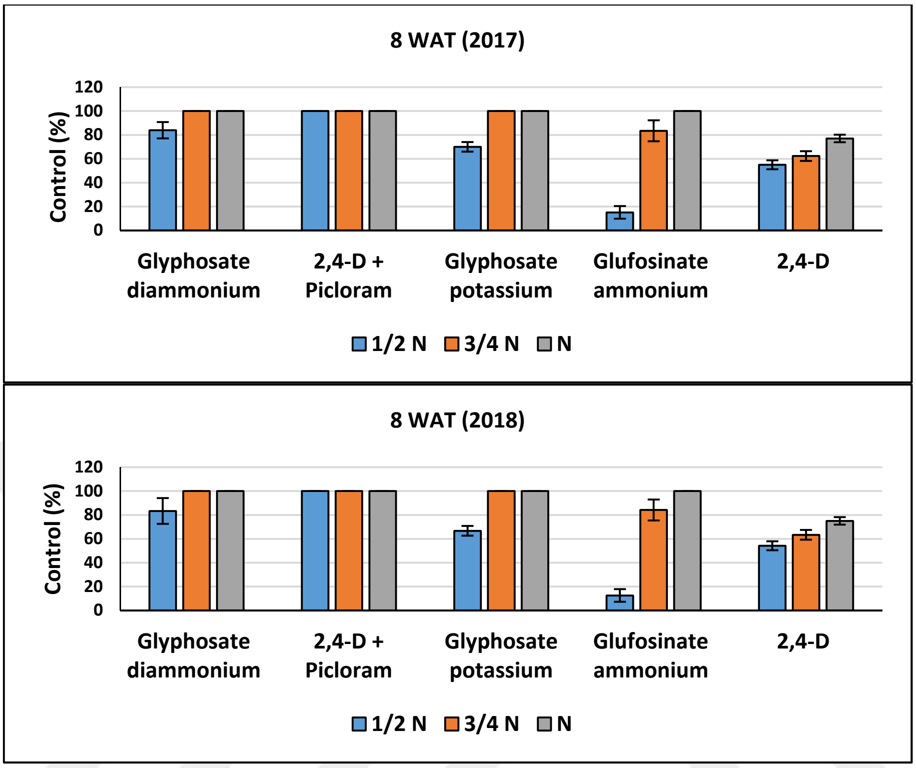


Figure 4.56. Percentage effect of five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on common mesquite [*Prosopis juliflora* (Sw.) DC.], under greenhouse conditions at the 8th week after herbicide application during two-year experiment (2017 and 2018).

4.4.2. Effect of Herbicides on the Growth of Common Mesquite [*Prosopis juliflora* (Sw.) DC.]

4.4.2.1. Effect of Glyphosate Diammonium

In the first year experiment, application of glyphosate di-ammonium resulted in 90.66%, 90.46% and 60%; 90%, 97% and 77.43%; 100%, 96.01% and 80.02%; and 100% 95.33 and 74.33% reduction in mesquite growth when sprayed at N (3392 g a.i ha^{-1}), 2/3 N (2261 g a.i ha^{-1}) and ½ N (1696 g a.i ha^{-1}) doses during 2nd, 3rd, 4th and 8th week of the experiment, respectively. However, in the second year, glyphosate diammonium caused 74.22%, 69.06% and 52.31%; 91.99%, 87.99% and 78.24%; 100%, 91.8 and 60.24%; and 100%, 89.73% and 46.47% reduction in the common mesquite growth at N, 2/3 N and ½ N doses during 2, 3, 4 and 8 WAT, respectively. Neal et al. (1985) found that the glyphosate uptake and translocation was largely associated with the growth stage of the woody plants. Therefore, in this study, the herbicide was found to be only effective on the dwarf mesquite during the shoot elongation stage (Fig. 4.57).

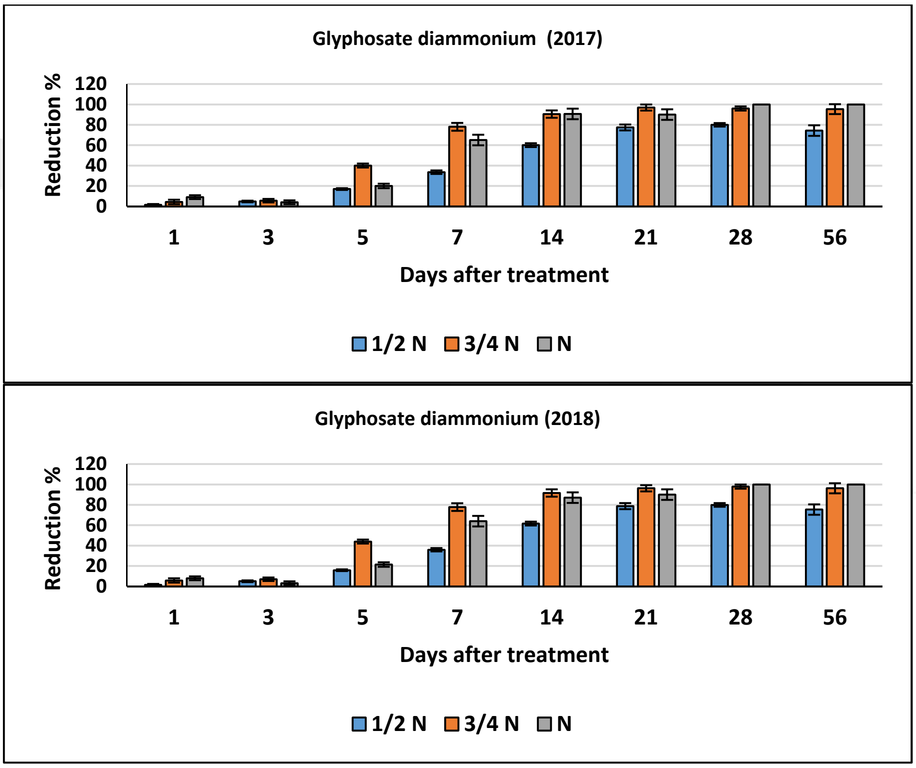


Figure 4.57. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.], after application of 424 g/l glyphosate di-ammonium at three doses (1/2 N, 2/3 N and N) during two-year experiment (2017 and 2018).

4.4.2.2. Effect of Glyphosate Potassium Salt

In the 2017 experiment, the glyphosate potassium has been shown to profoundly affect vegetative growth of common mesquite and significantly delayed its stand development, providing 100 % control at all doses. In 2018, the effect was continued until the end of the experiment, when 100%, 100% and 95.33% reduction in shoot growth were obtained on the 8th week with N (3969 g a.i ha^{-1}), 2/3 N (2646 g a.i ha^{-1}) and ½ N (1984 g a.i ha^{-1}) rates, respectively. Bentivegna et al (2017) concluded that the glyphosate treatment on weeds at early and advanced developmental stages was effectively reduced plant shoot height although the plants were remained alive. While in this study the common mesquite was completely controlled and there was no recovery observed (Fig. 4.58). Qasem, (2007) suggested two or more application of translocated herbicides such as glyphosate and 2,4-D to prevent regrowth of dwarf mesquite.

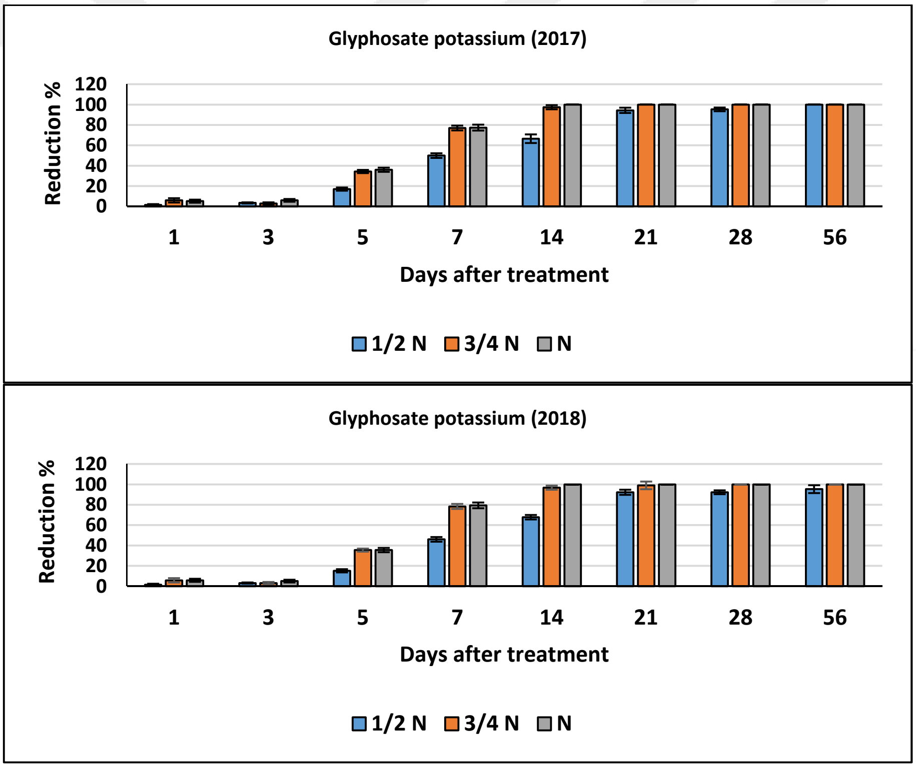


Figure 4.58. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] after application of 441 g/l glyphosate potassium salt at three doses (1/2 N, 2/3 N and N) during two-year experiment (2017 and 2018).

4.4.2.3. Effect of Glufosinate Ammonium

Starting from the second week of the first experiment, more than 50% reduction in mesquite growth has been provided by all glufosinate doses. However, recommended dose (1500 g a.i ha^{-1}) and two-third dose (1000 g a.i ha^{-1}) was observed to provide effective mesquite control; whereas percentage reduction in plant growth caused by the half dose (750 g a.i ha^{-1}) has been the least throughout the experiment. Ilango and Sreedhar (2001) reported that glufosinate ammonium at 0.3 0and 0.38 kg/ha gave a comparable weed control in tea fields for more than two weeks after treatment. Patra et al. (2016), reported that in some cases the reduced doses of glufosinate ammonium could be biologically more effective than the higher doses. Out results indicate the there was a decrease in the herbicide effectiveness, especially at the half and the two-thirds treatments (Fig. 4.59).

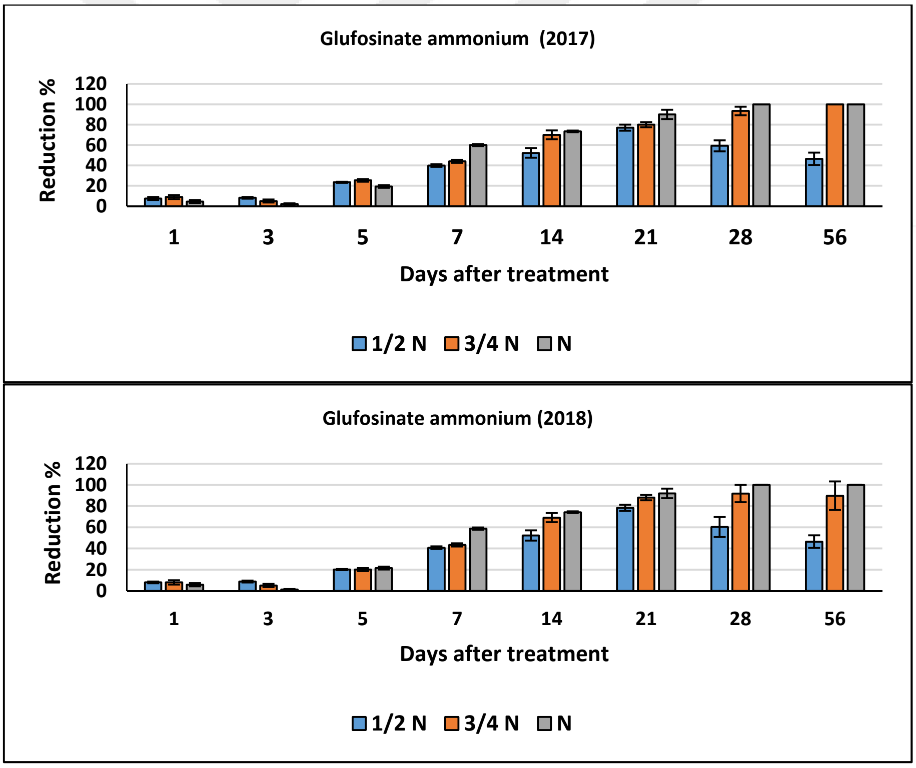
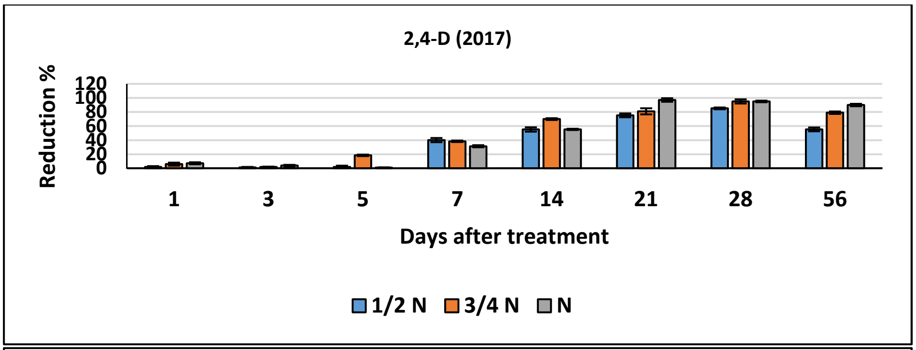


Figure 4.59. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.], after application of glufosinate ammonium at three doses (1/2 N, 2/3 N and N) during two-year experiment (2017 and 2018).

4.4.2.4. Effect of 2,4-D Amine

In the first experiment, application of 2,4-D amine on greenhouse-growing common mesquite seedlings at half dose (750 g a.i ha^{-1}), two-thirds (1000 g a.i ha^{-1}) and recommended (1500 g a.i ha^{-1}) rates provided (55.33%, 70% and 55.29%); (75.32%, 80.98% and 97%); (85.21%, 95% and 95%); and (55.33%, 79.11% and 90.04%) mesquite control during the 2, 3, 4 and 8 WAT, respectively. In the second year, (62.94%, 68.74% and 59.72%); (78.74%, 86.5% and 96%); (88.11%, 92.62% and 97.54%); and (79.14%, 82.57% and 86.61%) mesquite control was achieved by application of 2,4-D amine at ½ N, 2/3 N and N rates during the 2^{nd}, 3^{rd}, 4^{th} and 8^{th} WAT, respectively. However, in the 2018, the efficacy of 2,4-D amine was decreased during the period from the first month (97% at the recommended dose) to the second month (86.61% at recommended dose). Qasem (2007) reported good control results provided by 2,4-D amine against dwarf mesquite, especially in cases when the herbicide was applied more than one time. Akkkuzu, (2012), reported that 2,4-D amine was effectively controlled the dwarf mesquite. This may indicate that common mesquite has been able to survive the lethal dose of herbicide and recover after a relatively short time. As a result successful mesquite control with 2,4-D amine would require more than two application within the growing season. However, repeated application of herbicides with the same MOA might pose risks of triggering the herbicide resistance development in other weed species (Fig. 4.60).



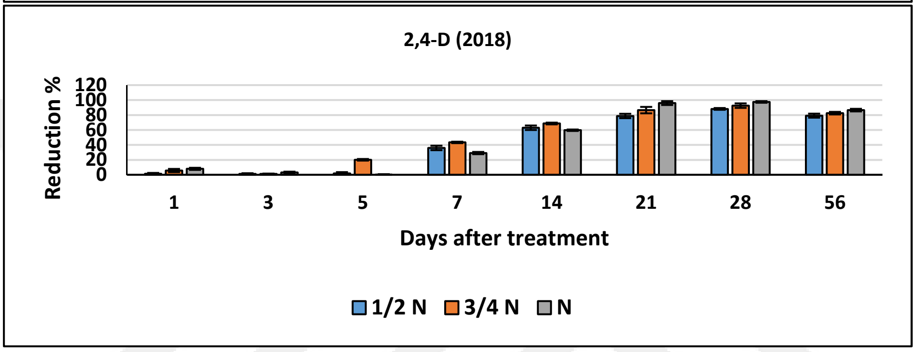


Figure 4.60. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] after application of 500 g/l 2,4-D amine salt at three doses (1/2 N, 2/3 N and N) during two-year experiment (2017 and 2018).

4.4.2.5. Effect of 2,4-D Tri-isopropylamine + Picloram

As observed in *P. farcta* case, similar results were obtained where 2,4-D triisopropylamine + picloram was demonstrated extreme effectiveness against *P. juliflors* at all examined application rates. Throughout the two-year experiments, 2,4-D+picloram provided complete (100%) reduction in mesquite growth only after two weeks of herbicide spraying. Moreover, more than 50% reduction in *P. juliflora* growth was observed with a week of herbicide application, showing rapid, and perhaps more importantly, sustainable prevention of common mesquite shoot growth. Jacoby et al., (1981) found that 3,6-Dichlorocolinic acid provided effective control of honey mesquite (*P. juliflora* var. *glandulosa*) compared to 2,4,5-T and 2,4,5-T+picloram. However, during the two experiment, the percentage reduction in plant growth caused by application of half dose was the same as that caused by the recommended dose (Fig. 4.61).

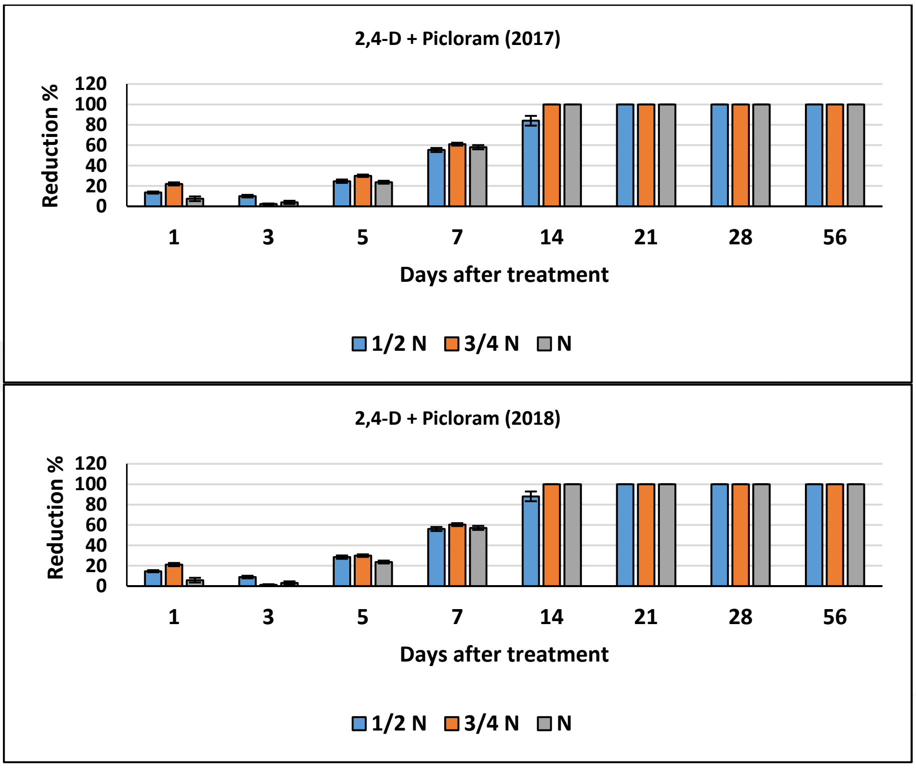


Figure 4.61. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] after application of 451.4 g/l 2,4-D tri-isopropylamine + 116.3 g/l picloram at three doses (1/2 N, 2/3 N and N) during two-year experiment (2017 and 2018).

4.4.2.6. Comparative Effect on Common Mesquite (*P. juliflora*) Growth

During the two experiments, no reduction has been observed in mesquite growth within one day of herbicide treatments (Fig. 4.62).

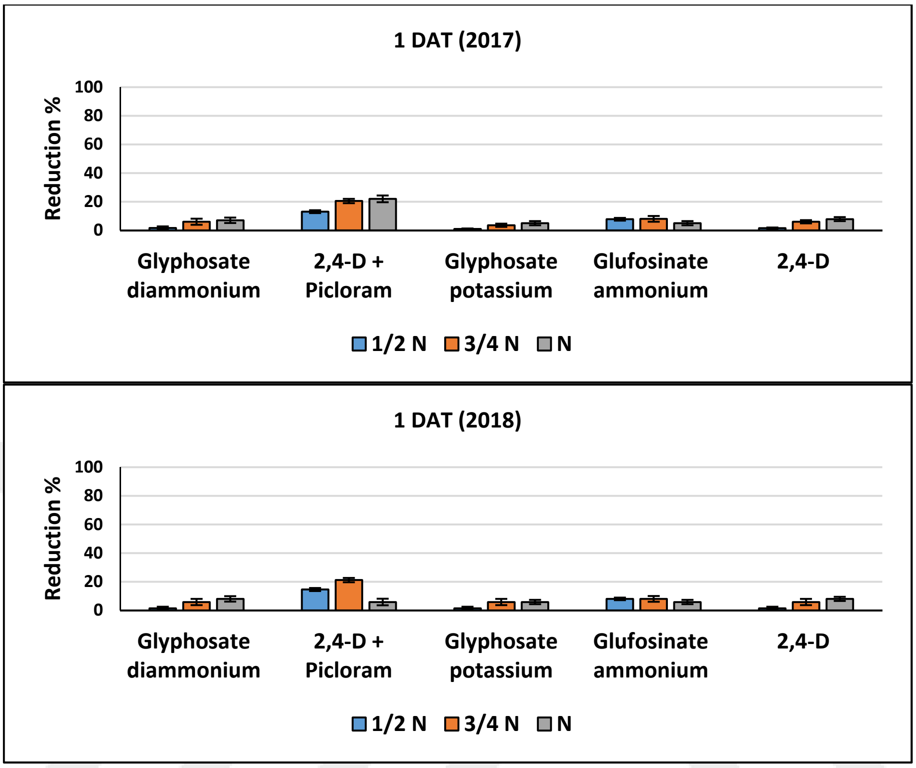


Figure 4.62. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 1st day after treatment during two-year experiment (2017 and 2018).

Similarly, no reduction in plant growth has been found after 3 days of herbicides application in any of the two-year experiments (Fig. 4.63).

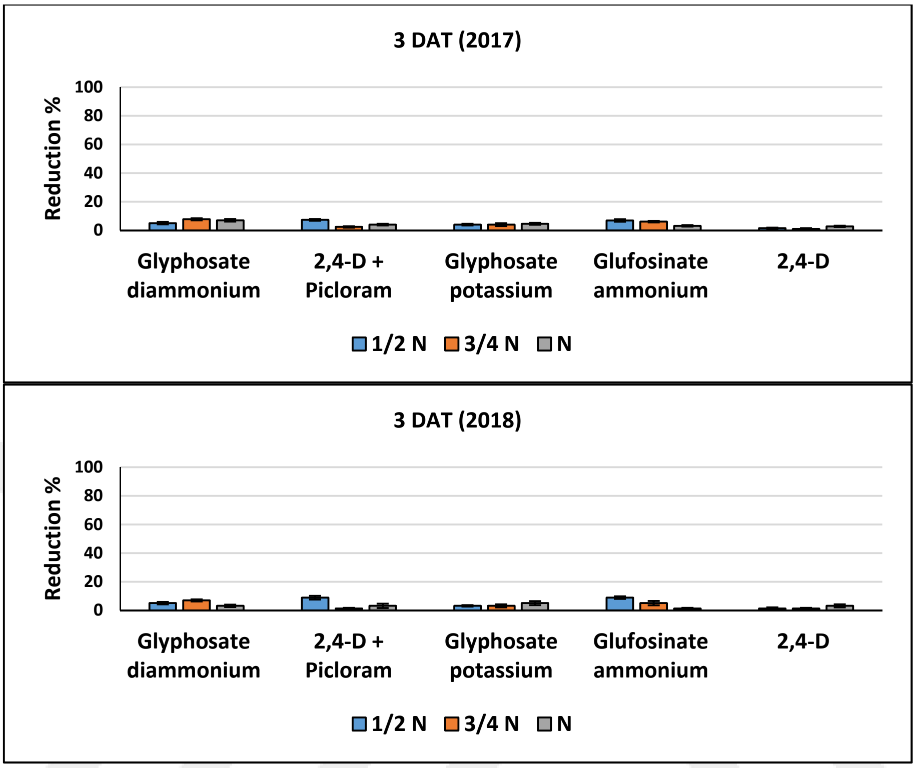


Figure 4.63. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 3rd day after treatment during two-year experiment (2017 and 2018).

Low, but visible reduction in growth of *P. juliflora* seedlings was obtained after five days of herbicide application. However, no herbicide treatment was found to cause 50% reduction during the two experiments (Fig. 4.64).

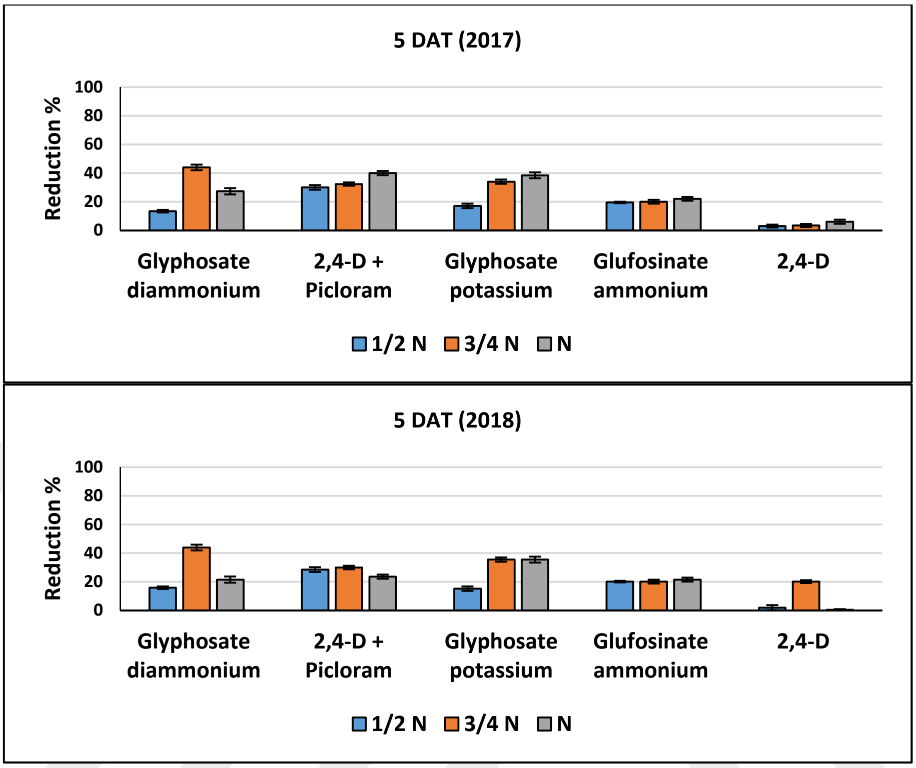


Figure 4.64. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 5th day after treatment during two-year experiment (2017 and 2018).

In the first week of the first experiment, except half dose treatments, all herbicides were significantly reduced growth of *P. juliflora* at their higher doses to approximately less than 50%. As reported by Jacoby et al., (1981), the 2,4-D+picloram treatments provided the highest percentage reduction in the mesquite growth during the 2017 experiments. Whereas, in parallel with Qasem, (2007), the glyphosate potassium provided the highest control in the 2018, relative to other herbicide treatments (Fig. 4.65).

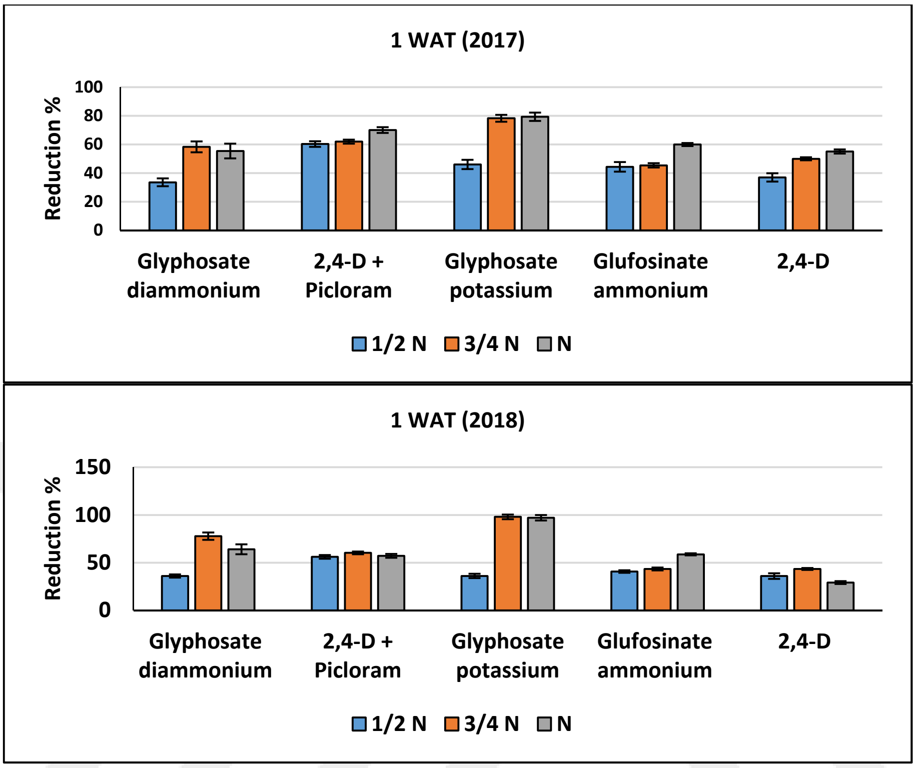


Figure 4.65. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 1st week after treatment during two-year experiment (2017 and 2018).

In the second week of the 2017 experiment, 2,4-D tri-isopropylamine, glyphosate potassium and glyphosate di-ammonium were found to be the most effective herbicides causing 100%, 100 and 90.38%; 100%, 100% and 65.77%; and 92.3%, 92.02% and 70% reduction in mesquite growth when applied at N, 2/3 N and ½ N rates, respectively. In the second experiment, the same herbicides provided the highest reduction in plant growth. In the other hand, lowest effeciency was observed in 2,4-D amine and glufosinate treatments (Fig. 4.66).

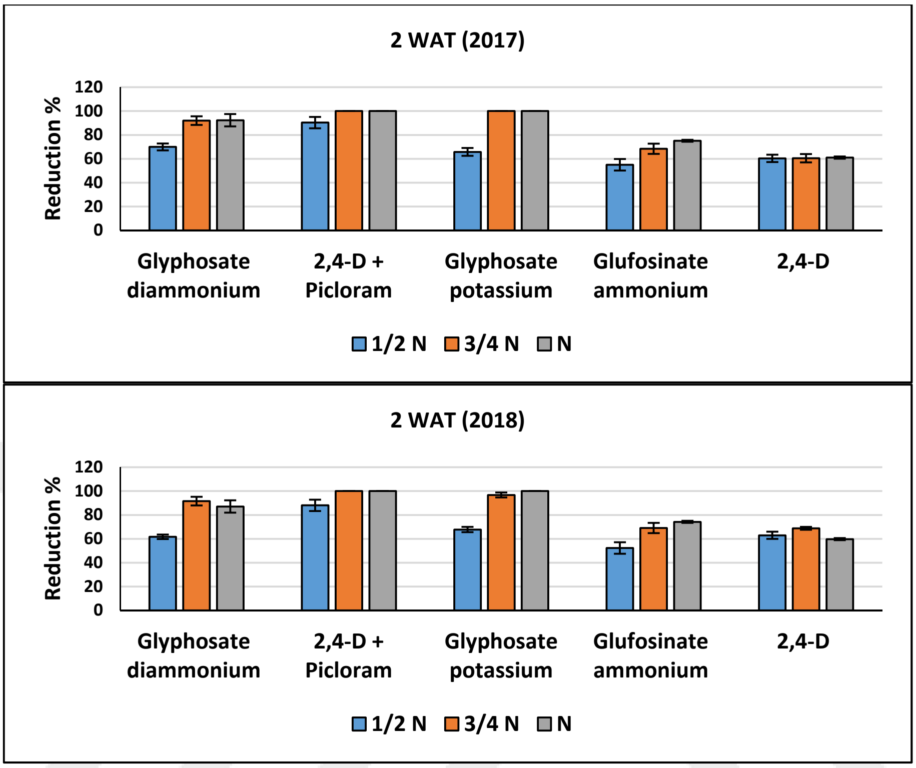


Figure 4.66. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 2nd week after treatment during two-year experiment (2017 and 2018).

Three weeks after herbicide applications, total eradication (100% control) of common mesquite seedlings was observed with three rates of 2,4-D plus picloram treatments during the two-year experiments. Additionally, the two glyphosate formulation provided sufficient mesquite control, followed by glufosinate ammonium and 2,4-D amine treatments. More interestingly, half doses of all herbicides were found to cause effective control of greenhouse-grown *P. juliflora* (Fig. 4.67).

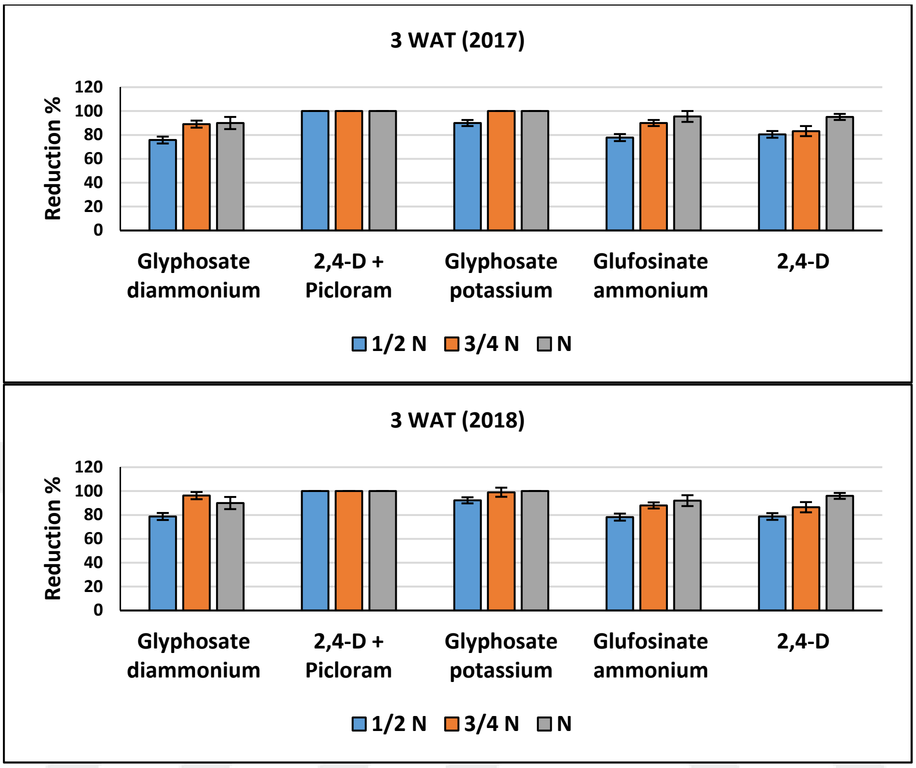


Figure 4.67. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 3rd week after treatment during two-year experiment (2017 and 2018).

For the two experiments, herbicide applications caused considerable disturbance in plant biophysiological processes resulted in reduced growth and delayed vegetative development. In the fourth day of the 2017 experiment, application of 2,4-D + picloram, glyphosate potassium, glyphosate di-ammonium, glufosinate-ammonium and 2,4-D amine provided 100%, 100%, 100%, 100% and 95.38% reduction in above-soil part of common mesquite at recommended doses, respectively. while the same herbicides caused 100%, 100%, 85.83%, 58.29% and 84.82% percentage growth reduction at their half doses (1/2 N), respectively. However, in 2018, 100%, 100%, 100%, 100% and 97.54% reduction in mesquite growth was obtained with application of 2,4-D + picloram, glyphosate potassium, glyphosate diammonium, glufosinate ammonium and 2,4-D amine at their recommended doses (N), respectively (Fig. 4.68).

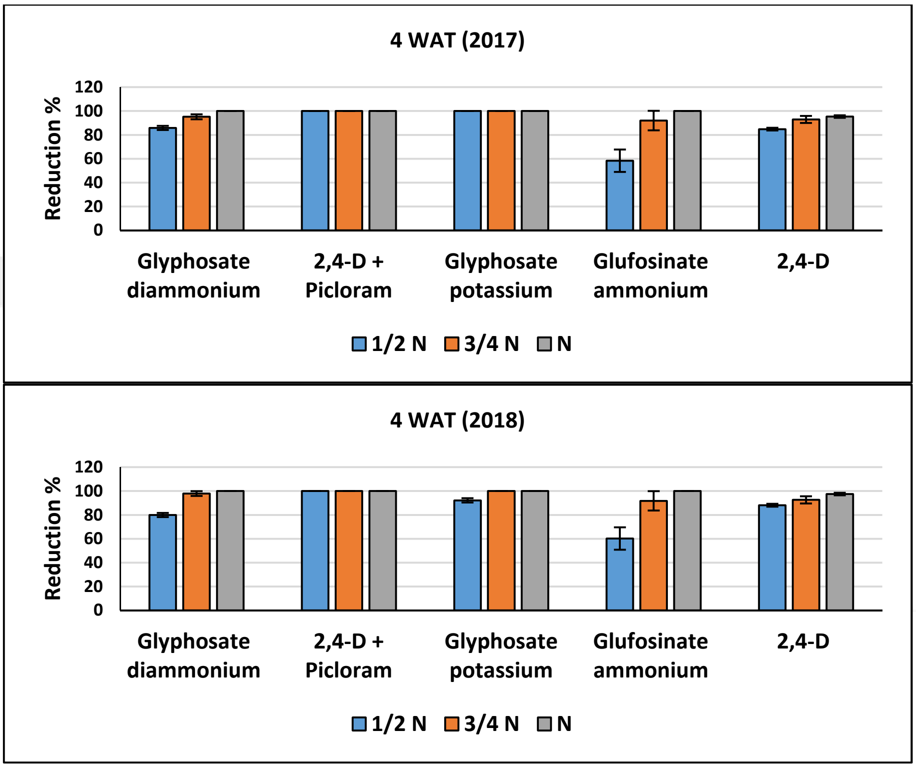


Figure 4.68. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 4th week after treatment during two-year experiment (2017 and 2018).

At the end of the first experiment performed in 2017, all herbicides effectively controlled the common mesquite at their recommended and two-third application rates. For instance, 2,4-D+picloram (100% and 100%); glyphosate potassium (100% and 100%); glyphosate di-ammonium (100% and 97%); glufosinate-ammonium (100% and 90%) and 2,4-D amine (85.77% and 81.27%)

were remarkably reduced mesquite growth. In 2018, the same activity was found with these herbicides, indicating that only mesquite plants treated with 2,4-D amine can recover after a single application. Feldman and Galvan, (1972) reported that the application of picloram mixed with diesel or kerosene on *Prosopis ruscifolia* as stump cut provided 83% control; and this was considered the most economical chemical treatment for mesquite control. This research come in agreement with what was reported in the previous studies (Fig. 4.69).

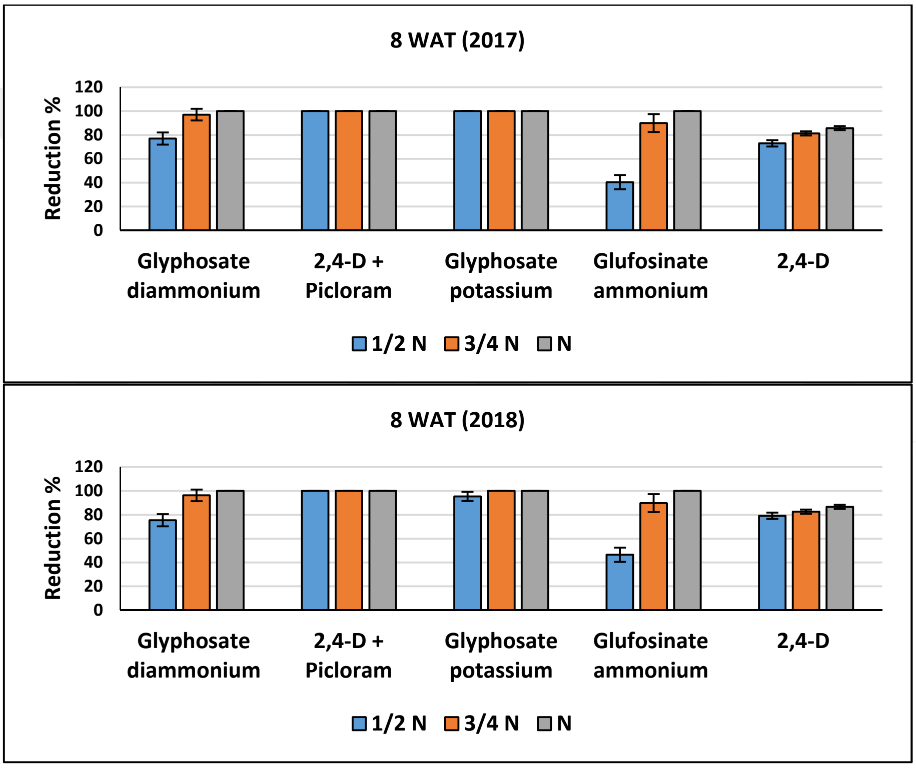


Figure 4.69. Percentage reduction in shoot height of common mesquite [*Prosopis juliflora* (Sw.) DC.] as affected by five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) at the 8th week after treatment during two-year experiment (2017 and 2018).

4.4.3. Effect of Herbicides on the Biomass of Common Mesquite [*Prosopis juliflora* (Sw.) DC.]

4.4.3.1. The Effect on the Fresh Weight

In 2017 experiment, of five tested herbicides, three herbicides were effectively reduced fresh weight (FW) of common mesquite. however, 2,4-D tri-isopropylamine treatments at its recommended, two-third and half doses led to 98.225, 98% and 95.95% reduction in fresh weight of mesquite, respectively. The second effective herbicide has been glyphosate potassium, causing loss in fresh weight by 93.76%, 83.78% and 69.43% with N, 2/3 N and ½ N rates, respectively. In 2018 experiment, 97.69%, 97.41% and 97.5% reduction in fresh weight were obtained with 2,4-D +picloram application at N, 2/3 N and ½ N rates, respectively. However, the lowest loss in fresh weight was found in 2,4-D amine treatment (Fig. 4.70).

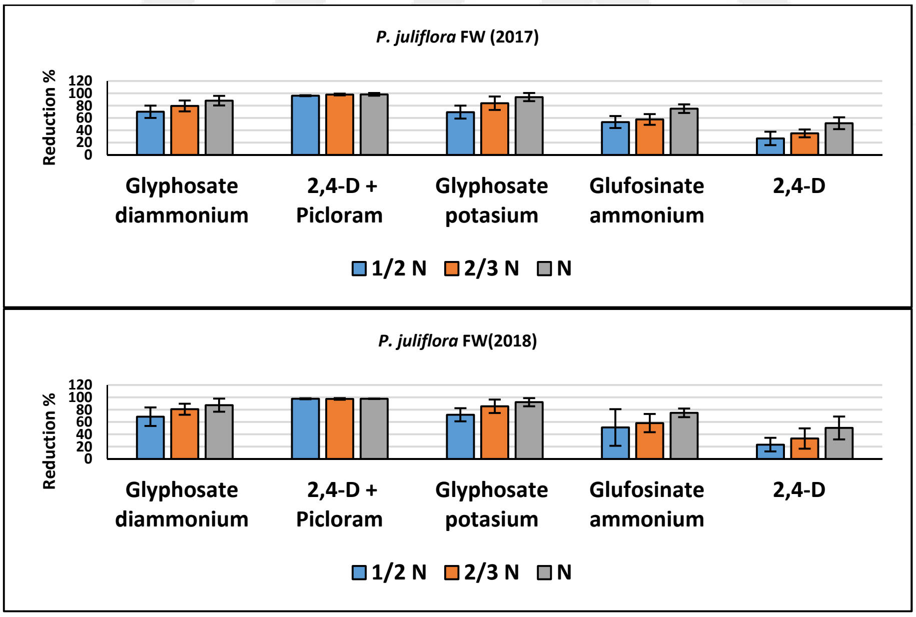


Figure 4.70. Effect of five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on the fresh weight (FW) of common mesquite [*Prosopis juliflora* (Sw.) DC.] during two-year greenhouse experiment (2017 and 2018).

4.4.3.2. The Effect on the Dry Weight

The dry weight of common mesquite was significantly affected by application of 2,4-D + picloram, glyphosate potassium, glyphosate di-ammonium and glufosinate ammonium treatments. In the first experiment, while premix herbicide decreased the total dry weight of mesquite by nearly 100%, 2,4-D amine decreased the dry weight by approximately 50%. Additionally, no significant differences in mesquite dry weight were determined in 2,4-D + picloram treatments. Almost similar results were found in the second year, where 2,4-D + picloram led to greatest dry mass loss and 2,4-D amine caused no difference in dry weight of treated and untreated seedlings. Qasem (2007), in a previous study has reported that the application of translocated herbicides such as glyphosate and 2,4-D would effectively control *P. farcta*, especially during the fallow season. Conversely, in this study, the glyphosate and 2,4-D amine apreared to be less effective compared to the rest of the herbicides tested (Fig. 4.71).

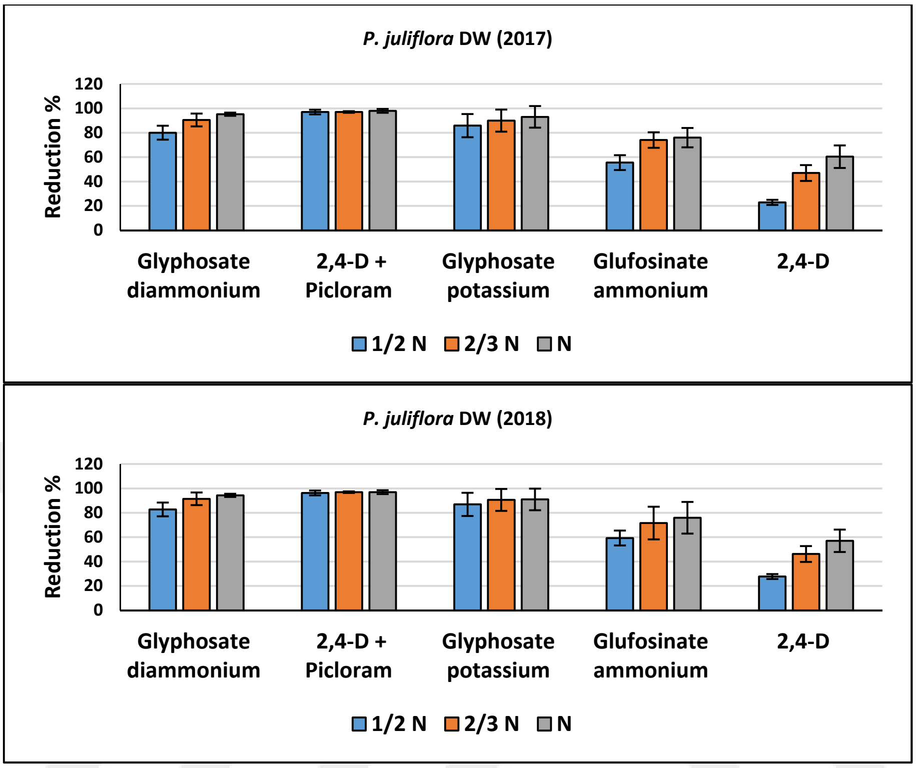


Figure 4.71. Effect of five herbicides (glyphosate di-ammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses on the dry weight (DW) of common mesquite [*Prosopis juliflora* (Sw.) DC.] during two-year greenhouse experiment (2017 and 2018).

4.5. Chemical Control of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] under Field Conditions

4.5.1. Percentage Control of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.]

4.5.1.1. Effect of Glyphosate Diammonium Salt

The highest control provided as a result of glyphosate diammonium application in the first experiment has been recorded in the 2^{nd} WAT, where 79.5%, 60.76% and 62.43%mesquite control was caused by the recommended (3392 g a.i ha^{-1}), two-third (2261 g a.i ha^{-1}) and the half doses (1696 g a.i ha^{-1}), respectively.

At the end of the experiment, mesquite control observed was 16.19%, 19% and 37.39% at ½ N, 2/3N and N rates, respectively. In 2018, the recommended, two-third and half dose treatments provided 60%, 58.75% and 81% control of dwarf mesquite during the first two weeks, respectively. However, a significant decline in herbicide effectiveness was found by the end of the experiment, as the percentage control achieved by the recommended dose of herbicide was found to decrease from 84% during the 3rd week to 46.75% during the 8th week. Qasem, (2007) reported that glyphosate-based herbicides have proven considerable efficacy against dwarf mesquite recovery. In contrast, our results indicate that the herbicidal effect of glyphosate can take only several days for *P. farcta* to fully recover (Fig. 4.72).

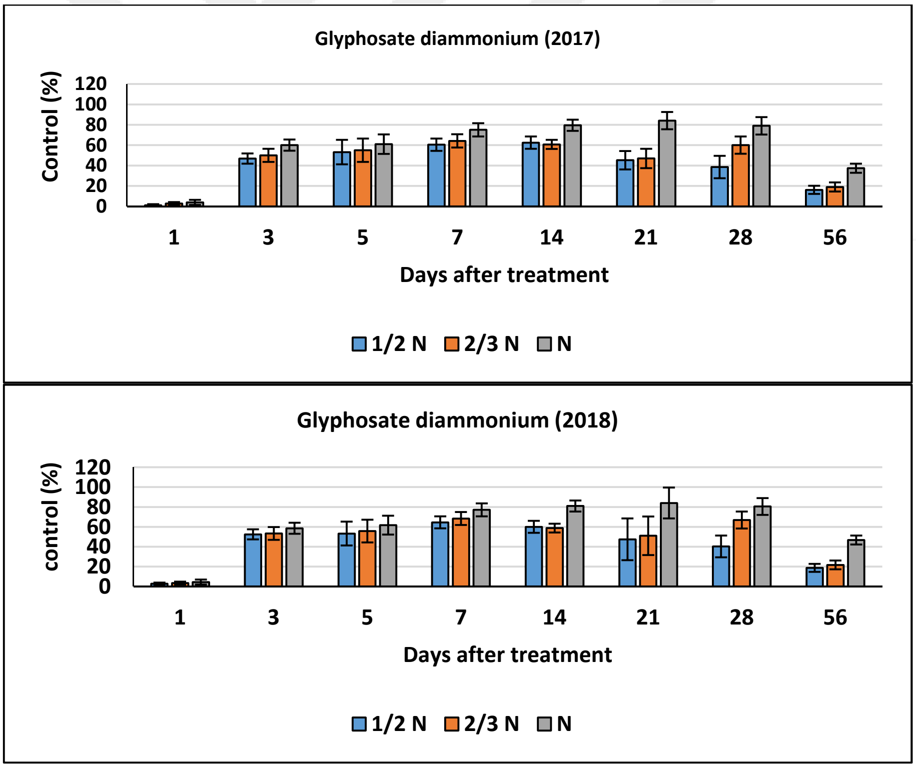


Figure 4.72. Percentage effect of 424 g/l glyphosate di-ammonium salt applied under field conditions on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.].

4.5.1.2. Effect of Glyphosate Potassium

In the two field experiments, almost all glyphosate potassium treatments caused no significant effect on dwarf mesquite. The highest mesquite control was obtained when glyphosate was applied at 3969 g a.i ha^{-1} (N) rate leading to 69.28% and 70% mesquite control during the first and second experiment, respectively. It has been suggested that dwarf mesquite resumed vegetative growth just few days after application of glyphosate potassium. Although previous research conducted by Ganie et al., (2017), suggested that the glyphosate absorption and translocation has been improved at higher temperatures, our results showed that from the second week after treatment, the efficacy of glyphosate was significantly decreased and this may indicate that consecutive increase in soil temperature in the summer months increased the water absorption by the plants which in turn improved plant recovery and led to a significant decrease in the herbicidal efficacy of glyphosate (Fig. 4.73).

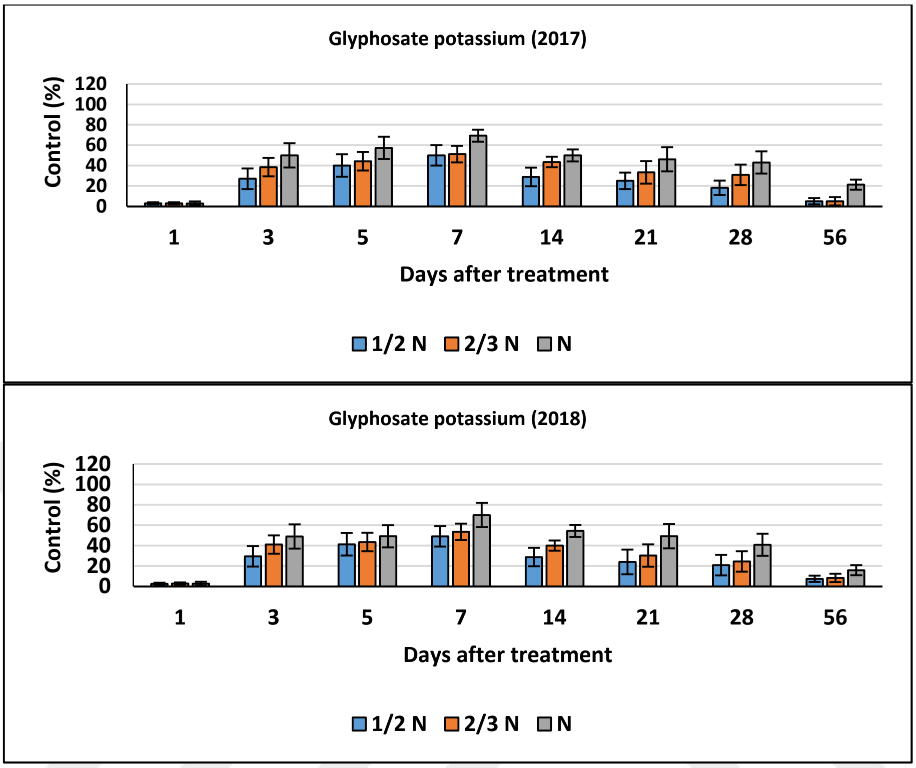


Figure 4.73. Percentage effect of 441 g/l glyphosate potassium on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], under field conditions.

4.5.1.3. Effect of Glufosinate Ammonium

Throughout experiments, the three doses of glufosinate ammonium provided significant control of dwarf mesquite only 3 DAT. In the first-year study, the highest control was recorded in the first week after treatment, when glufosinate was applied at 1500 g a.i ha^{-1} (N), 1000 g a.i ha^{-1} (2/3 N) and 750 g a.i ha^{-1} (½ (N) resulted in 90%, 80% and 75.83% control, respectively. In the second-year study, the highest control was also observed on the first week, when 88.75%, 85.03% and 79.26% control percentages were obtained at N, 2/3 N and ½ N rates, respectively. This may indicate that the herbicide rate could be reduced to 50% while still provide the same efficacy (Fig. 4.74).

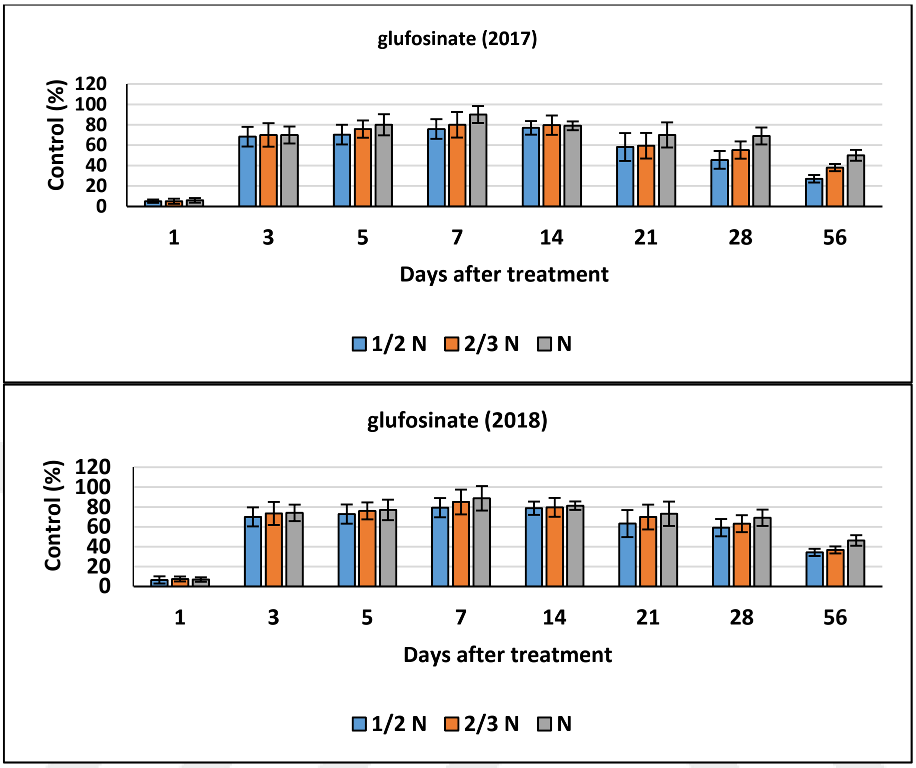


Figure 4.74. Percentage effect of 200 g/l glufosinate ammonium applied under field conditions on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.].

4.5.1.4. Effect of 2,4-D Amine

Application of 2,4-D amine on dwarf mesquite, even its label-recommended dose caused relatively low control when compared to other herbicides. Greatest mesquite control provided by 2,4-D at recommended dose was 73.26% in the second week of first the experiment; and 78.59% during the first week of second experiment. However, by the end of the experiment, this percentage control which provided by the recommended dose was decreased to 50% in the first study and 40.87% in the second study. No previous studies available on the effect of soil temperature on herbicidal efficacy of 2,4-D against *P. farcta*. However, Derr and Serensits (2016) and Ganie et al. (2017) reported that warm air temperatures have increased 2,4-D efficacy against broadleaf weed species compared to cold temperatures. Our results revealed that the continuous increase in soil temperature might be the indirect reason for the declined 2,4-D effectiveness against *P. farcta* (Fig. 4.75).

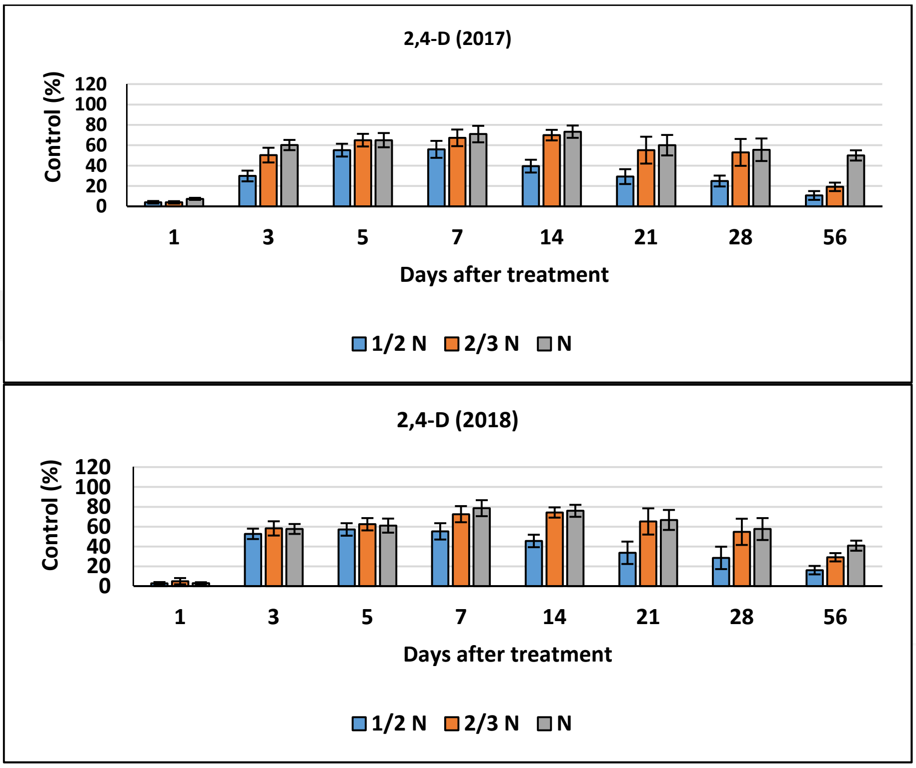


Figure 4.75. Percentage effect of 500 g/l 2,4-D applied under field conditions on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.].

4.5.1.5. Effect of 2,4-D Tri-isopropylamine + Picloram

Visual estimates of dwarf mesquite control in field conditions showed the 2,4-D plus picloram performance to be the greatest until the end of the study. Generally, dwarf mesquite seemed sensitive to 2,4-D + picloram and responded very quickly (3 days) after herbicide application. In 2017 study, the percentage control reached 88, 87.77 and 78.33% at N (5677 g a.i ha^{-1}), 2/3 N (3784 g a.i ha^{-1}) and ½ N (2838 g a.i ha^{-1}) rates in the first week; and the effect was continued increasing steadily until reached 100%, 100% and 86.37 control at the last day of the experiment for the recommended, two-third and half doses, respectively. In 2018 study, roughly similar results have been obtained in the first week of herbicide application, when percent control provided by N, 2/3 N and ½ N rates of 2,4-D + picloram was 98%, 86.12% and 81.8%, respectively. The same application rates, recommended, two-third and half doses, caused 100%, 84.5% and 66%, which indicates steady and successful control of dwarf mesquite can be achieved by this herbicide (Fig. 4.76). The results obtained from this study confirm what found by Evans and Young (1975) that application of 2,4-D plus picloram was more effective than 2,4-D alone.

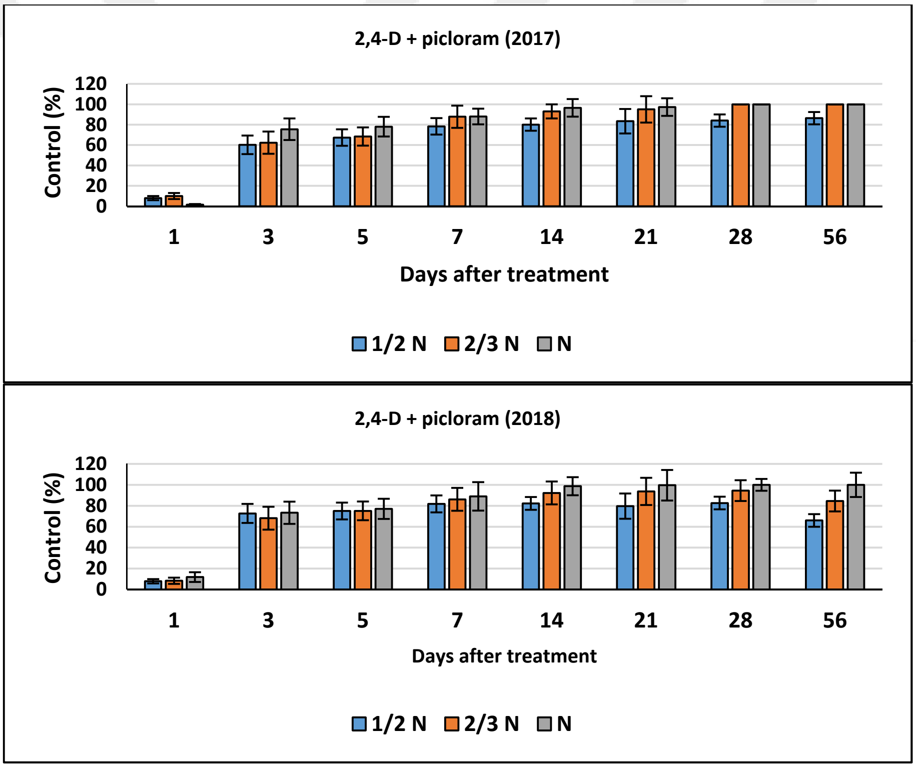


Figure 4.76. Percentage effect of 451.4 g/l 2,4-D tri-isopropyl amine + 116.3 g/l picloram applied under field conditions on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.].

4.5.1.6. Comparative Percentage Control of Dwarf Mesquite (*P. farcta*)

Both for 2017 and 2018 experiments, no herbicidal effect was observed on dwarf mesquite in the first DAT (Fig. 4.77).

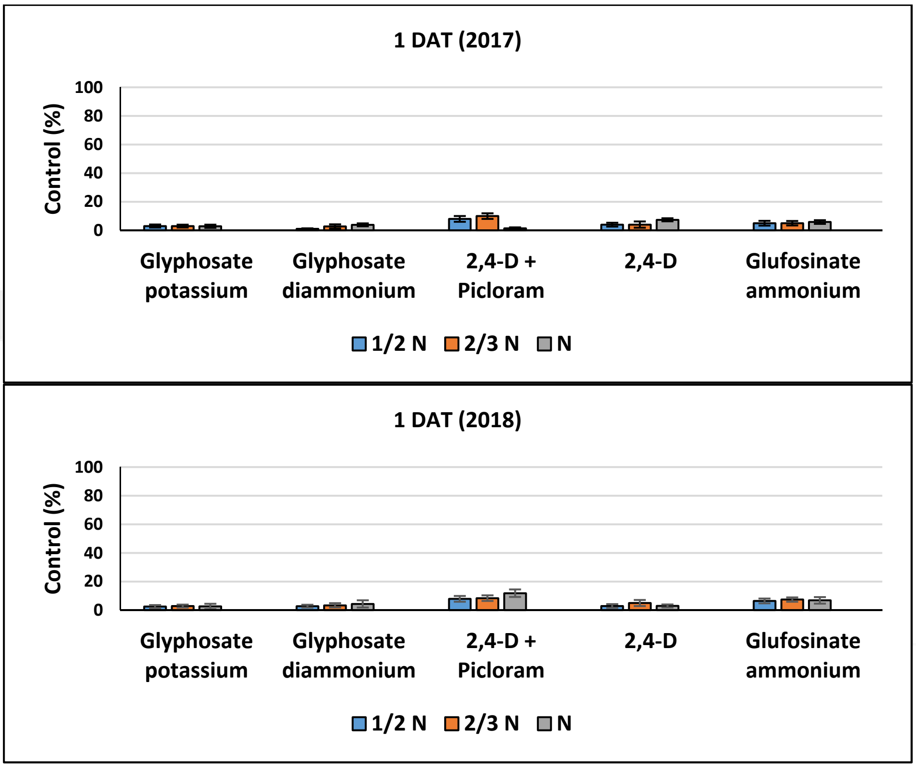


Figure 4.77. Percentage mesquite control provided by five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied at three doses under field conditions at the 1st day after herbicide application during two-year experiment (2017 and 2018).

In the third day of herbicides application, highest control was found in glufosinate ammonium treatment, providing 70%, 70% and 68.32% control of dwarf mesquite at 1500 g a.i ha^{-1} (N), 1000 g a.i ha^{-1} (2/3 N) and 750 g a.i ha^{-1} (1/2 N) rates, respectively. In 2018, there was a slight increase in the herbicidal effectiveness of the reduced doses of the 2,4-D amine. However, all the other herbicides caused relatively the same mesquite control as that of the first year (Fig. 4.78).

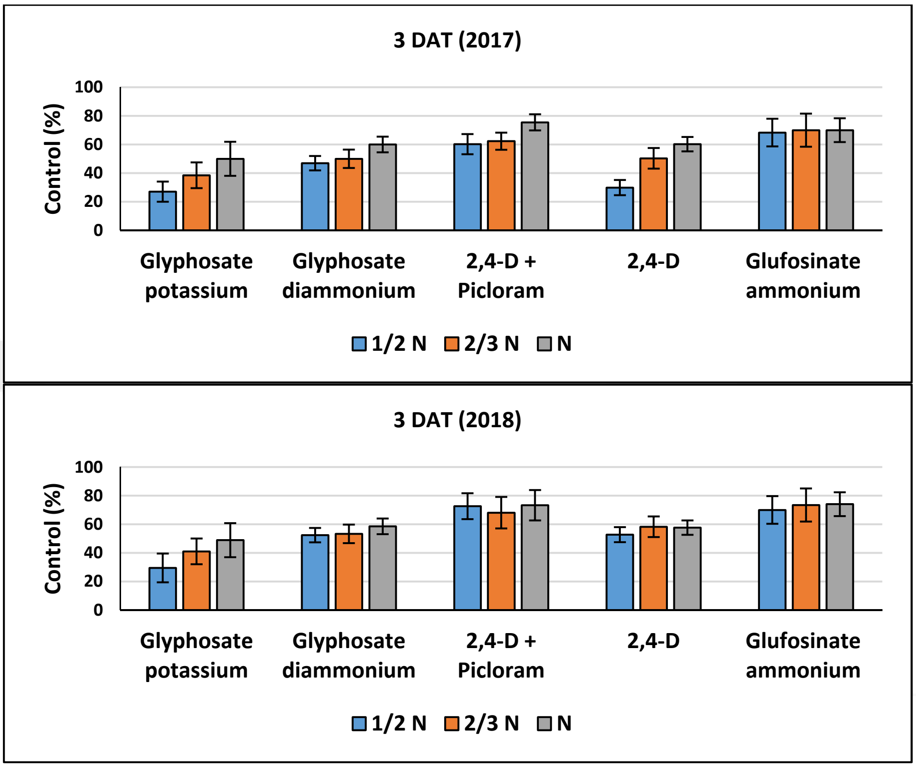


Figure 4.78. Percentage mesquite control provided by five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses under field conditions at the 3rd day after herbicide application during two-year experiment (2017 and 2018).

Five DAT, Except for glyphosate potassium treatments, all herbicide provided sufficient mesquite control even with their half doses. In the 2017 experiment, however, the highest percentage control caused by half dose was found in glufosinate treatment (70.33%), followed by 2,4-D plus picloram (67.34%), 2,4-D amine (55.25%), glyphosate diammonium (53.2%) and glyphosate potassium (40%). Similarly, the highest effect achieved by recommended dose was found in glufosinate treatment (80%), followed by the recommended doses of the 2,4-D plus picloram (78%), 2,4-D amine (65%), glyphosate diammonium (60.98) and glyphosate potassium (57.29). In the 2018 experiment, despite the fact that 2,4-D plus piloram seemed to be more effective than glufosinate, there were no significant differences between the two herbicides in terms of biological effect on dwarf mesquite (Fig. 4.79).

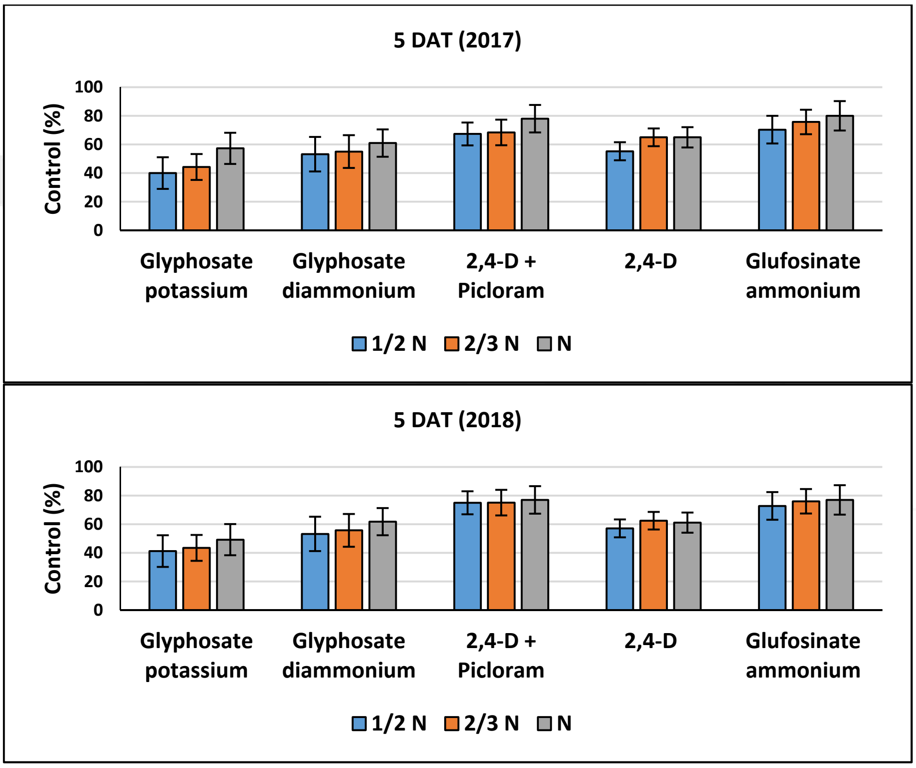


Figure 4.79. Percentage mesquite control provided by five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses under field conditions at the 5th day after herbicide application during two-year experiment (2017 and 2018).

In the first week of the two-year experiment, no herbicide was found to cause less than 50% control of *P. farcta*. In the other hand, 2,4-D plus picloram and glufosinate provided the same high level of control with no statistical difference among their three rates. However, dwarf mesquite has shown to be more sensitive to glufosinate ammonium than all glyphosate formulations. As it has been described by Bethke et al. (2013), this performance could be attributed to the rapid absorption and fast action of glufosinate compared to slow systematic action of glyphosate. During the two experiments, the lowest effect was observed in glyphosate potassium and 2,4-D amine treatments (Fig. 4.80). Previous research has suggested that poor uptake of 2,4,5-T by mesquite was been correlated with the translocation of nutrients and organic materials from soil, which is largely affected by different environmental factors such as temperature, light, water and organic matter (Dahl et al, 1971).

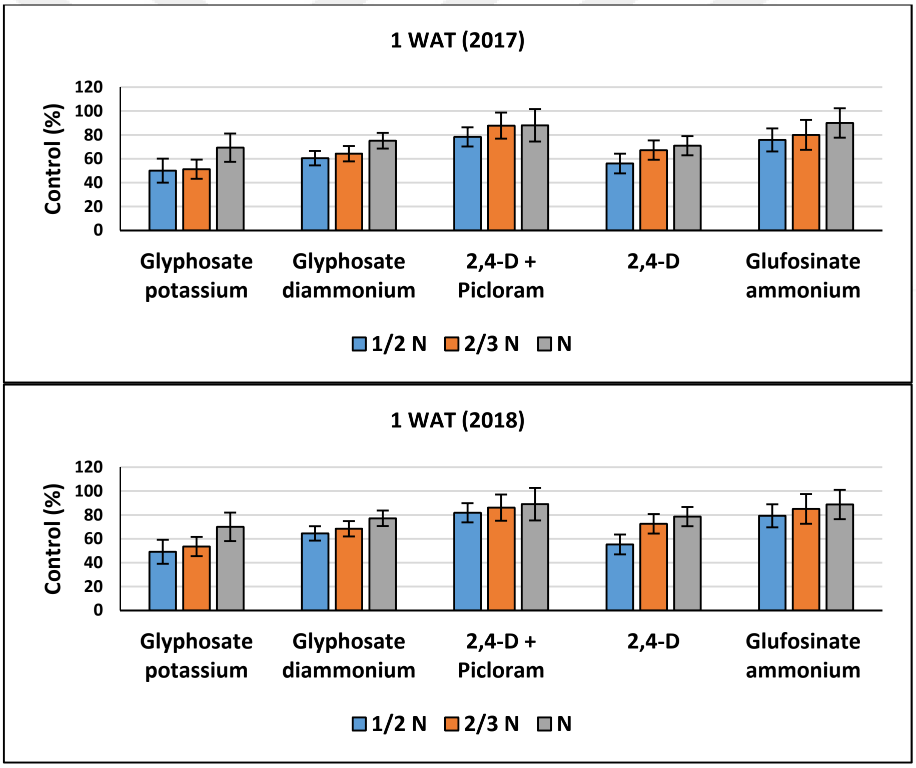


Figure 4.80. Comparative mesquite control provided by five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses under field conditions at the 1st week after herbicide application during two-year experiment (2017 and 2018).

During the first experiment, effectiveness of 2,4-D plus picloram was raised from 88% in the first week to approximately 100% in the second week. While the effect of glufosinate on *P. farcta* declined from 90% in the first week to about 79% in the second week. The least mesquite control was found in glyphosate potassium, glyphosate diammonium and 2,4-D amine. In 2018, glyphosate potassium was observed to be ineffective against dwarf mesquite (Fig. 4.81).

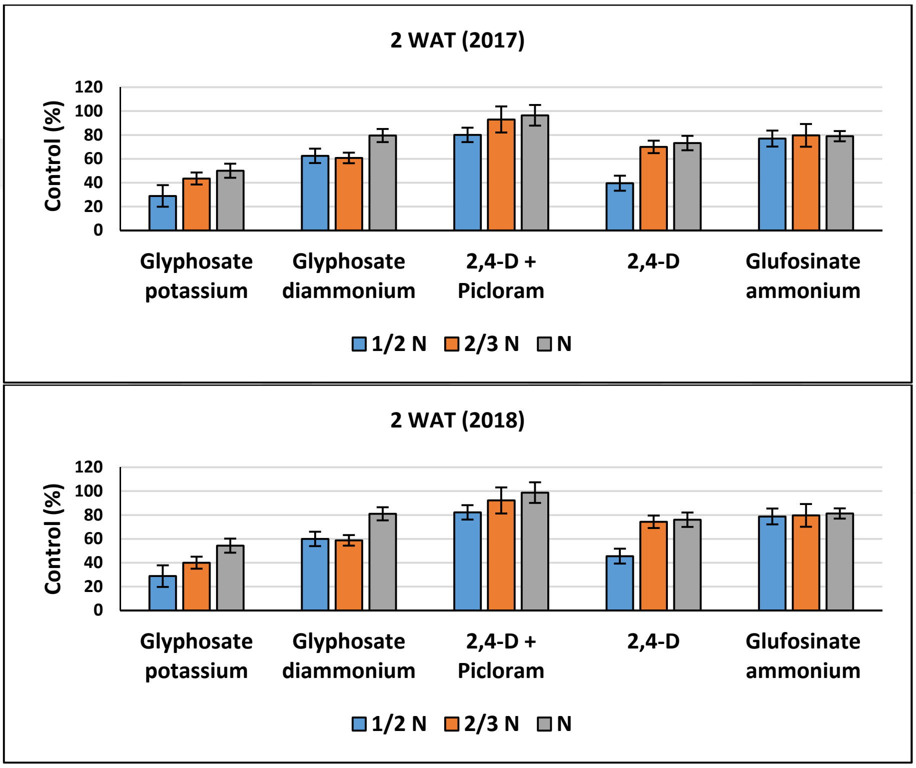


Figure 4.81. Comparative mesquite control provided by five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses undefield conditions at the 2nd week after herbicide application during two-year experiment (2017 and 2018).

As shown below, glyphosate di-ammonium was found to be more effective against dwarf mesquite than glyphosate potassium under field conditions. However, 2,4-D plus picloram and glufosinate demonstrated severe death and growth suppression on mesquite damage and other weed species. As described before, 2,4-D amine has been apparently inactive against dwarf mesquite (Fig. 4.82).

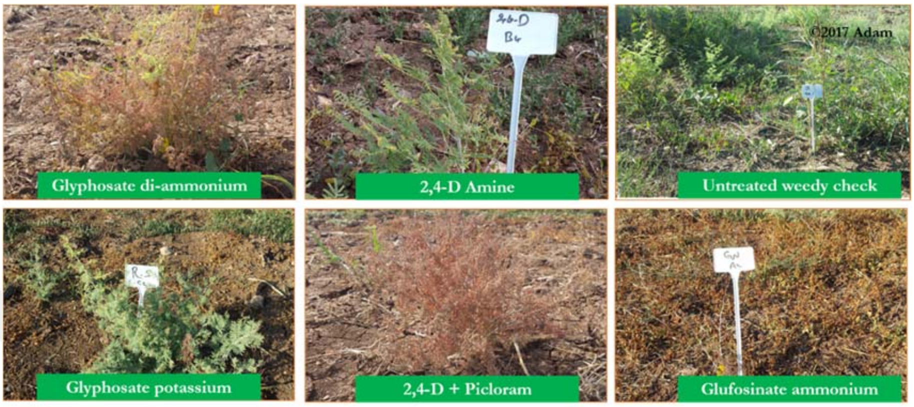


Figure 4.82. Effect of five herbicides on dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] under field conditions in the second week after herbicide treatment during 2017 experiment.

During the third week, only 2,4-D plus picloram was appeared to remain effective at its three doses, while efficacies of all other herbicides were significantly reduced. For example, in the two experiments, the average weed control provided by recommended doses of glufosinate and glyphosate potassium was decreased to nearly 70% and 50%, respectively (Fig. 4.83).

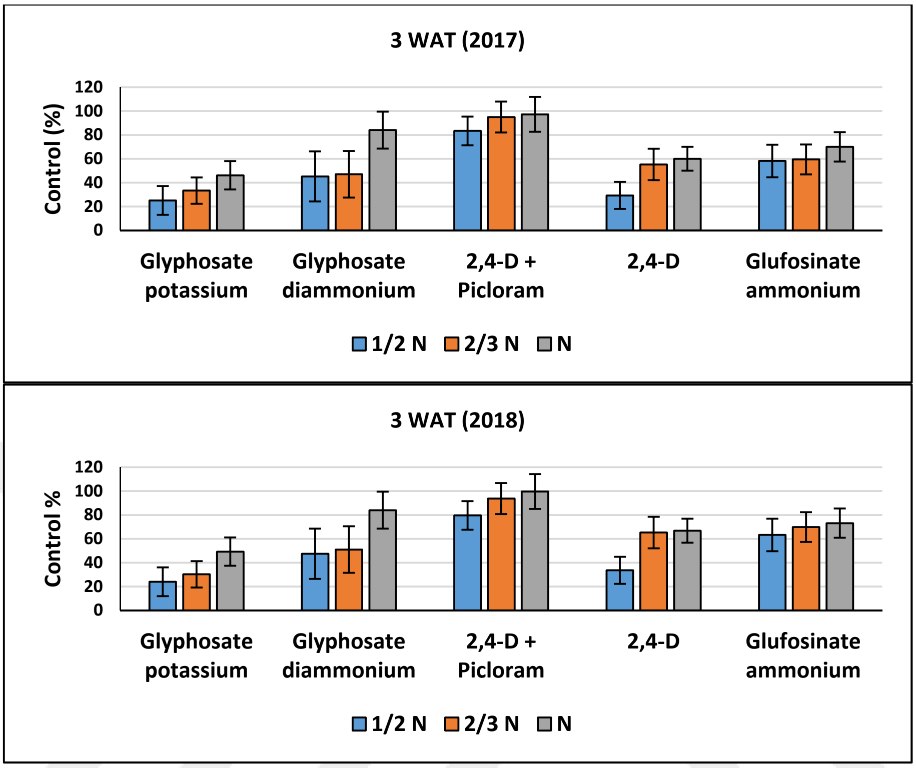


Figure 4.83. Comparative control provided by five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses undefield conditions at the 3rd week after herbicide application during two-year experiment (2017 and 2018).

For the two-year experiments, one month after herbicide applications, only plots treated with 2,4-D+picloram were found to be effective against dwarf mesquite, causing 100%, 100% and 84% control in the first year and 100, 94.5 and 82.62 percent control during the second year experiment at N (5677 g a.i ha^{-1}), 2/3 N (3784 g a.i ha^{-1}) and (2838 g a.i ha^{-1}) rates, respectively. However, except the recommended dose of glyphosate di-ammonium, all herbicides provided significantly inefficient control at all rates (Fig. 4.84).

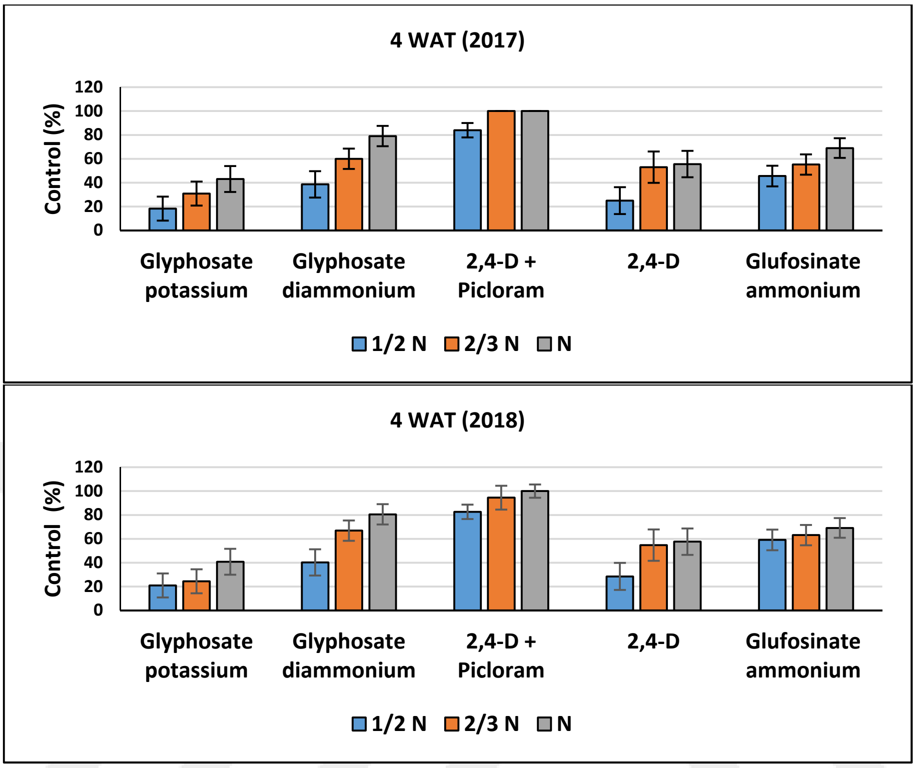


Figure 4.84. Comparative control provided by five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses undefield conditions at the 4th week after herbicide application during two-year experiment (2017 and 2018).

At the end of the first experiment (2017), while the 2,4-D plus picloram achieved the highest mesquite control (near to 100%), there has been a significant reduction in the effectiveness (near to zero in some cases) of the other herbicides. For instance, the effectiveness of 2,4-D lasted only several days, indicating that dwarf mesquite has been able to recover and resume its vegetative development after being exposed to lethal dose of 2,4-D. in 2018, 2,4-D+picloram achieved 100, 85.5 and 66% control, which has been efficient to manage drawf mesquite populations. However, the percentages of mesquite control provided by glufosinate ammonium (46.25, 36.75 and 34.25%), 2,4-D amine (50, 19.22 and 16.15%), glyphosate diammonium (46.75, 21.62 and 18.58%) and glyphosate potassium (15.87, 8.25 and 7.37%) were worryingly not enough to suppress the weed infestations properly (Fig. 4.85).

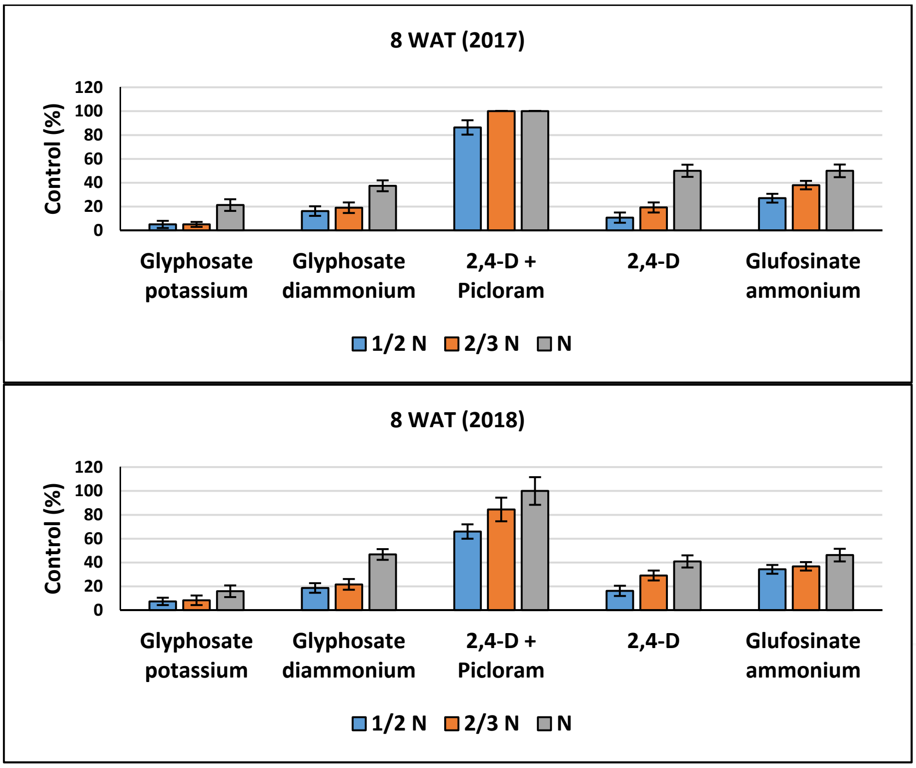


Figure 4.85. Comparative control provided by five different herbicides (glyphosate diammonium, glyphosate potassium, glufosinate ammonium, 2,4-D amine and 2,4-D + picloram) applied in three doses undefield conditions at the 8^{th} week after herbicide application during two-year experiment (2017 and 2018).

4.5.2. Effect of Herbicides on Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.] Growth

4.5.2.1. Effect of Glyphosate Diammonium Compared to the Weedy Check

In this study, the herbicidal effects resulting from glyphosate diammonium treatment have been observed clearly after three weeks of foliar application, where caused 70%, 55% and 50.3% reduction in *P. farcta* growth with N (3392 g a.i ha^{-1}), 2/3 N (2261 g a.i ha^{-1}) and ½ N (1696 g a.i ha^{-1}) rates, respectively. However, percentage reduction in growth of dwarf mesquite provided by recommended dose was gradually decreased from 70% in the 3rd WAT to 60% at the end of the experiment. Neal et al. (1985) reported that glyphosate absorption and translocation was largely affected by the growth stage of woody ornamentals, *Juniperus conferta* and *Ligustrum japonicum* and glyphosate was found to be more effective when plant was been at shoot elongation stage. Contrastingly, despite being applied on dwarf mesquite at the 33 BBCH stage, glyphosate diammonium has shown least control compared to the untreated control checks (Fig. 4.86). In a previous study conducted by Qasem (2007), reported that glyphosate was effectively controlled *P. farcta* growth and recovery.

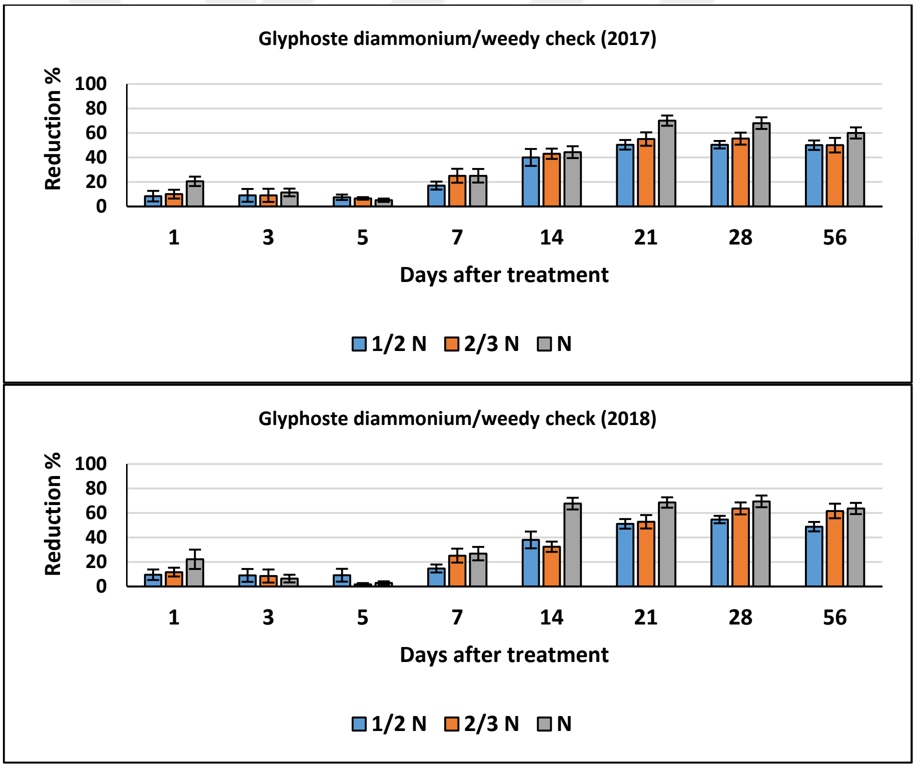


Figure 4.86. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], compared to the untreated weedy check as affected by application of 424 g/l glyphosate diammonium salt under field conditions.

4.5.2.2. Effect of Glyphosate Diammonium Compared to the Weed-free Check

As compared to the untreated weed-free controls, relatively good effect on dwarf mesquite was observed 2 WAT. In the first-year experiment, foliar application of glyphosate di-ammonium provided 80%, 81.5%, 80% and 80% growth reduction at recommended dose; 52.18%, 65%, 70% and 55.28% reduction at two-third dose; and 50%, 60%, 70% and 50% reduction at half dose, during the 2^{nd}, 3^{rd}, 4^{th} and 8^{th} WAT, respectively. In the second-year experiment, the same herbicide caused 76.02%, 75.65%, 76.2% and 72.95% reduction at recommended dose; 49.9%, 63.43%, 71.7% and 71.36% reduction at two-third dose; and 54.02%, 62.12%, 64.63% and 61.83% growth reduction at half dose, during the 2, 3, 4 and 8 WAT, respectively. However, effect of glyphosate diammonium was found to be higher when compared to the untreated weed-free checks, and this was due to the fact that the plants grow in weed-free areas were taller and more develpped than those in weed-infested areas. Therefore, when the growth of the treated plants were compared to that of the untreated weed-free plants, then the difference was significantly greater (Fig. 4.87).

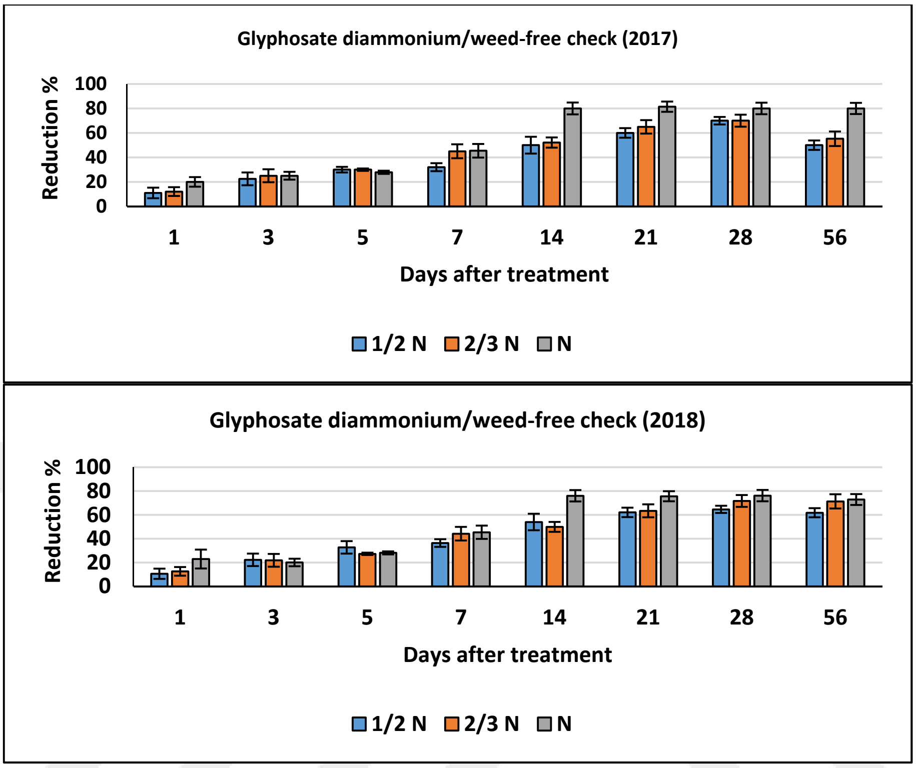


Figure 4.87. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], compared to the untreated weed-free check as affected by application of 424 g/l glyphosate diammonium salt.

4.5.2.3. Effect of Glyphosate Potassium Compared to the Weedy Check

During the 2017 field experiment, the highest growth reduction (64%) achieved by the glyphosate potassium relative to the untreated weedy check was recorded in the recommended dose (3969 g a.i ha^{-1}) on the 4^{th} week after treatment. There were significant differences between percentage reductions caused by different application rates. However, the percentage reduction in the vertical growth of dwarf mesquite provided by the ½ N and 2/3 N was (15, 25.83, 20.3 and 30%) and (27, 35.33, 36 and 30%) during the 2, 3, 4 and 8 WAT, respectively. In 2018, the foliar application of glyphosate potassium resulted in (15, 27 and 50%) in the 2^{nd} week; (25.93, 35.33 and 53%) in the 3^{rd} week; (20.3, 36 and 51.02%) in the

4th week; and (30, 30 and 40%) in the 8th week, at the ½ N, 2/3 N and N doses, respectively. In a previous study, Scroggs et al. (2009) found that glyphosate potassium was provided successful weed control when applied alone. Mueller et al. (2006) reported no significant difference among three different glyphosate salts (isopropylamine, di-ammonium and potassium) in terms of herbicidal efficacy. However, our study revealed that potassium salt of glyphosate has been less effective against dwarf mesquite (Fig. 4.88).

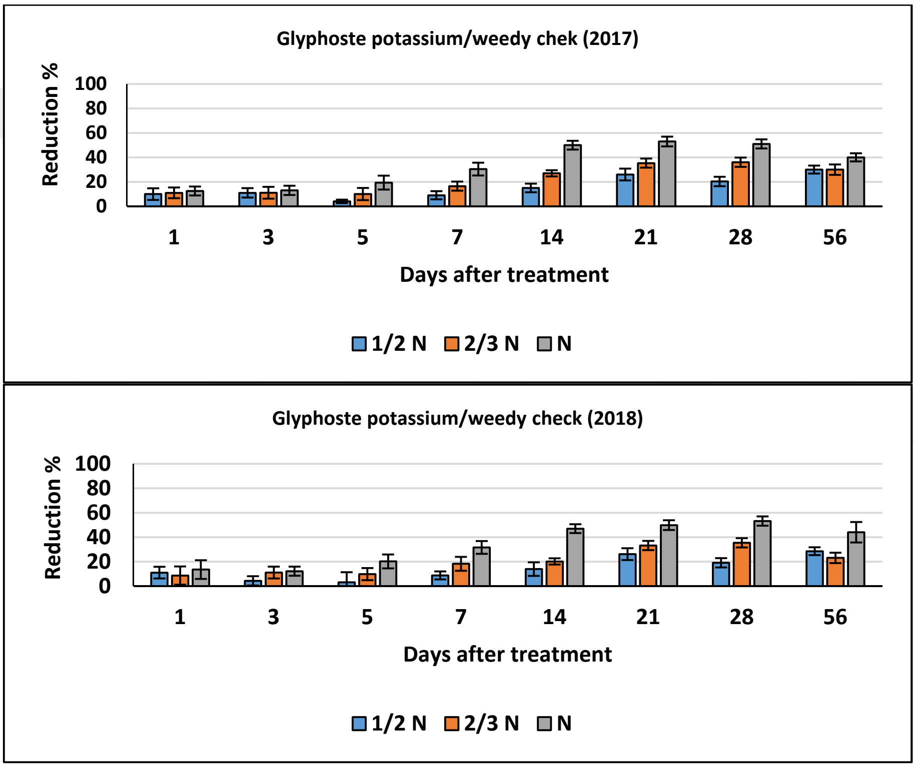


Figure 4.88. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], compared to the untreated weedy check as affected by application of 441 g/l glyphosate potassium salt during two-year experiment (2017 and 2018).

4.5.2.4. Effect of Glyphosate Potassium Compared to the Weed-Free Check

Compared to non-herbicide, weed-free plots, glyphosate potassium provided a slight reduction in dwarf mesquite growth, even at high rates. In the first year, the maximum reduction in mesquite growth at the recommended dose (3969 g a.i. ha^{-1}) was 57.41%, 60%, 64% and 60.02% during the 14, 21, 28 and 56 DAT, respectively. Similarly, in the second year, greatest reduction recorded at the recommended dose of glyphosate potassium was 60.69%, 61.13%, 63.52 and 58.29% during 14, 21, 28 and 56 DAT, respectively (Fig. 4.89). Bovey et al. (1990) attested that glyphosate isopropylamine was been less effective against huisache (*Acacia farnesiana*) and honey mesquite (*Prosopis glandulosa*) compared to the potassium salt of picloram.

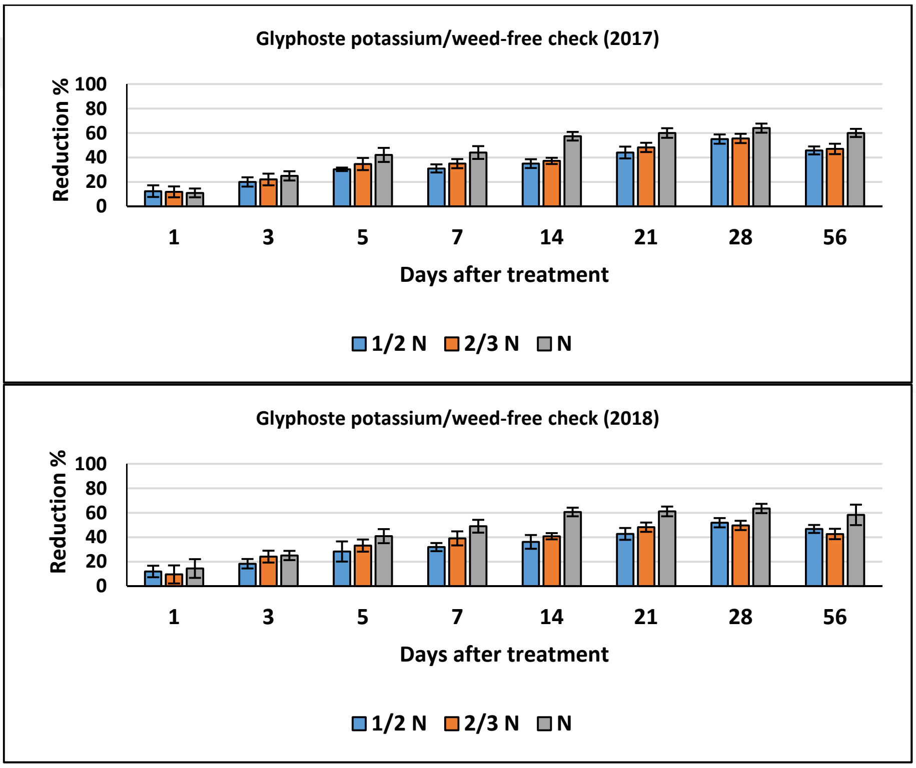


Figure 4.89. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], compared to the untreated weed-free check as affected by foliar application of 441 g/l glyphosate potassium salt during two years experiment during 2017 and 2018 experiments.

4.5.2.5. Effect of Glufosinate Ammonium Compared to the Weedy Check

Promisingly, the effectiveness of glufosinate ammonium on dwarf mesquite seemed to be more stable and sustainable for a period of about 2 months, compared to many other herbicides. However, efficacy of glufosinate has taken three weeks to be observed on mesquite shrub. In 2017 study, percentage reduction provided by glufosinate ranged from 64.32% and 60.32% at N and 2/3N rates in the third week to 70% and 49.29% at N and 2/3N rates at the end of experiment. While in 2018 study, N and 2/3N rates of glufosinate ammonium resulted in 57.66% and 57.46% growth reduction at the 3rd week; and 61.12% and 56.75% growth reduction at the last day of the experiment. However, compared to greenhouse study results, glufosinate was found to be less effective under field conditions (Fig. 4.90). Similar has been reported by Mucheri (2016) where glufosinate provided excellent control of ryegrass in greenhouse than in field conditions.

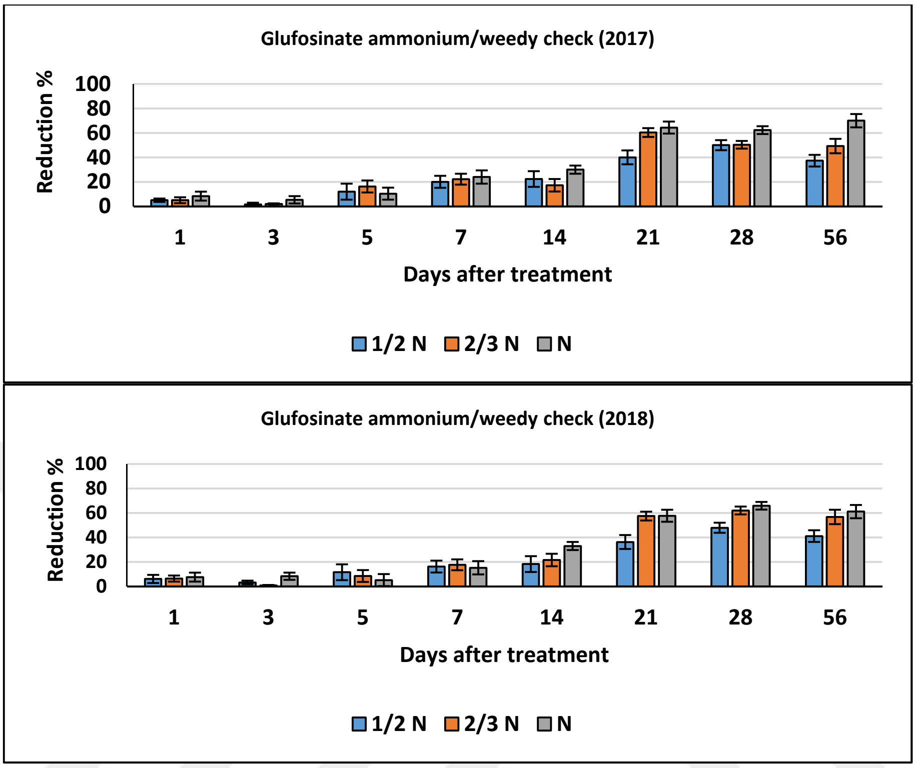


Figure 4.90. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], compared to the untreated weedy check as affected by foliar application of 200 g/l glufosinate ammonium during two years experiment (2017 and 2018).

4.5.2.6. Effect of Glufosinate Ammonium Compared to the Weed-Free Check

Growth of dwarf mesquite shoot was significantly reduced as a result of glufosinate application at different doses. During the first experiment, highest growth reduction was observed in the 4th week after herbicide application. Interestingly, 80, 73 and 55 percent reduction in dwarf mesquite growth was obtained with application of N (1500 g a.i. ha^{-1}), 2/3 N (1000 g a.i. ha^{-1}) and ½ N (750 g a.i. ha^{-1}) doses, respectively. During the second-year experiment, almost the same results were found during the 4th week. Long-term mesquite control with glufosinate ammonium and there was no difference between different application rates. Wibawa et al. (2009) reported great weed control efficacy achieved by glufosinate ammonium applied in oil palm plantations (Fig. 4.91).

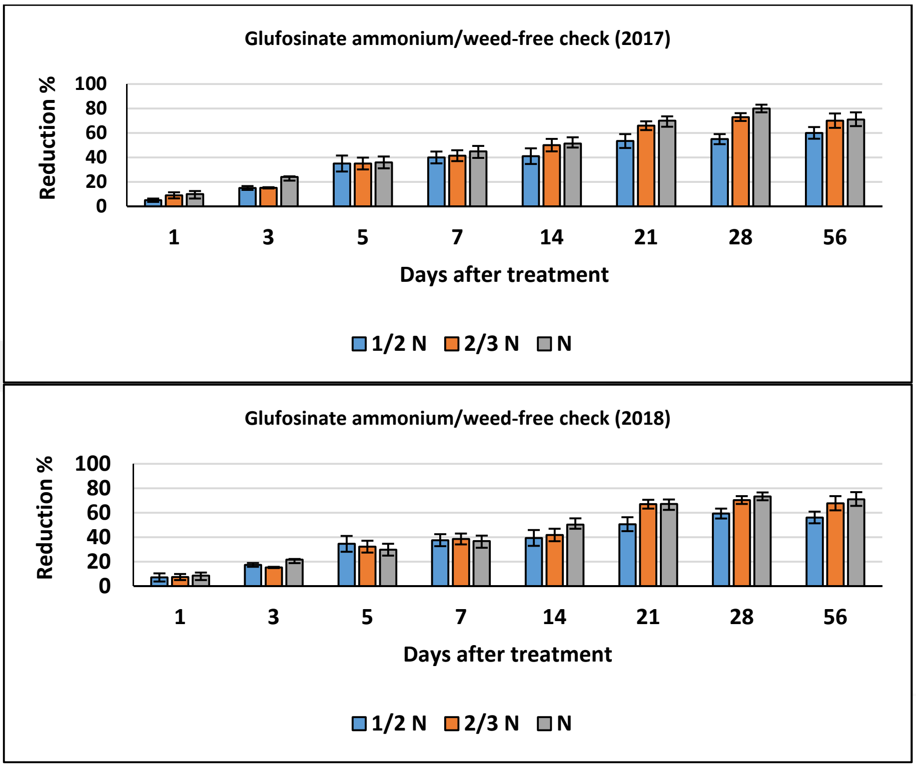


Figure 4.91. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], compared to the untreated weed-free check as affected by application of 200 g/l glufosinate ammonium during two years experiment.

4.5.2.7. Effect of 2,4-D Amine Compared to the Weedy Check

Throughout the two-year experiments, dwarf mesquite has proven high tolerance to the growth regulating herbicide, 2,4-D amine applied ta label-recommended dose. Generally, all doses of 2,4-D amine caused less than 50% reduction in shoot growth when compared to untreated controls. Highest reduction (63%) in plant shoot was recorded with recommended dose (1500 g a.i. ha^{-1}) during the 4th WAT (Fig. 4.92). Effective control of dwarf mesquite was reported with aerial application of 2,4-D ester (Qasem, 2007). However, in this research, reduction in plant growth provided by 2,4-D amine was insufficient.

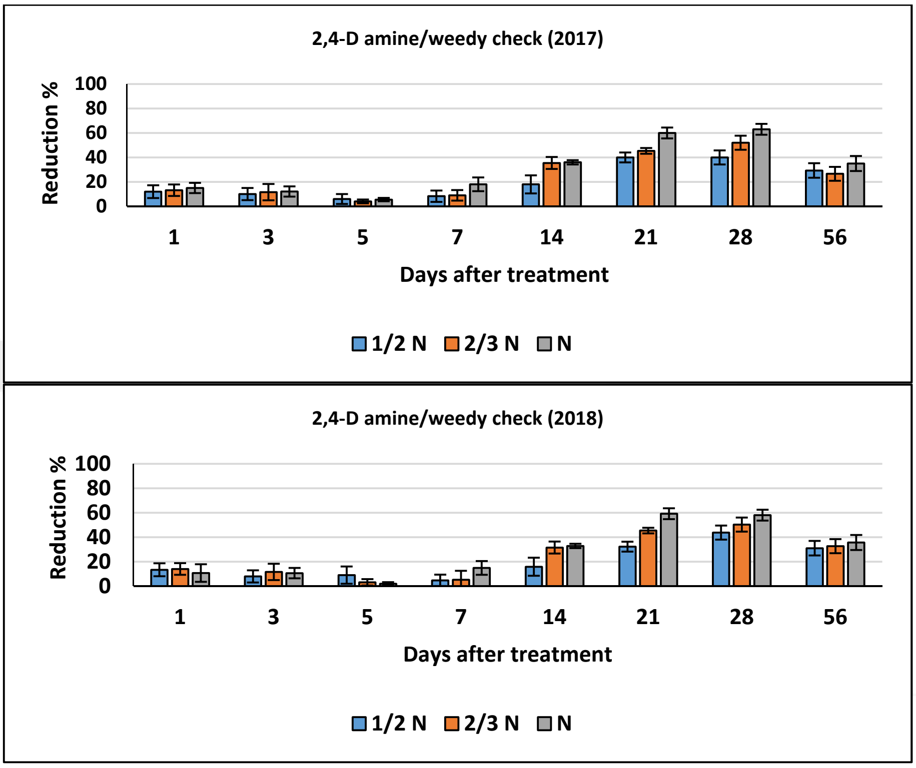


Figure 4.92. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], compared to the untreated weedy check as affected by application of 500 g/l 2,4-D amine during experiments conducted in 2017 and 2018.

4.5.2.8. Effect of 2,4-D Amine Compared to the Weed-Free Check

In 4th week of the 2017 experiment, 71.07, 64 and 55% reduction in dwarf mesquite growth, relative to weed-free check, was observed as a result of 2,4-D amine applied at N, 2/3 N and ½ N doses, respectively. Similarly, in 2018, the highest growth reduction was recorded in the 3rd and 4th WAT, where the recommended dose of the 2,4-D amine resulted in 68.44% and 67.31%, respectively (Fig. 4.93).

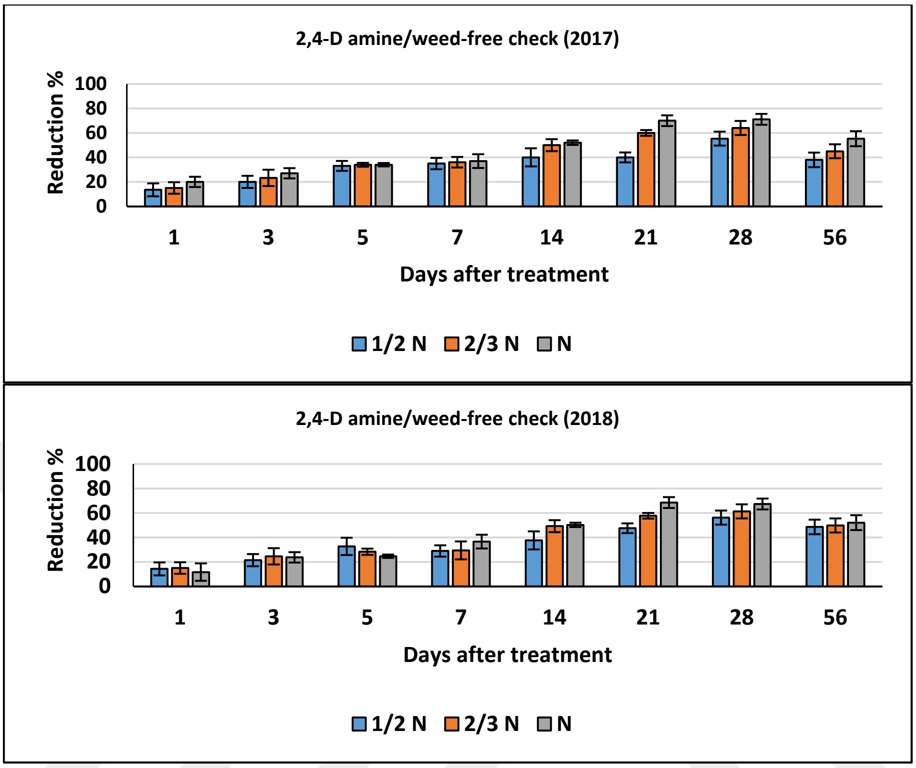


Figure 4.93**.** Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], compared to the untreated weed-free check as affected by application of 500 g/l 2,4-D amine during two years-experiment (2017 and 2018).

4.5.2.9. Effect of 2,4-D + Picloram Compared to the Weedy Check

Application of 2,4-D plus picloram led to elimination of significant proportion of dwarf mesquite shoot. Starting from the second week after herbicide application, excellent results were obtained with the recommended (5677 g a.i. ha^{-1}) and two-third (3784 g a.i. ha^{-1}) doses. At the end of the first experiment, 100%, 99% and 8634% reduction were provided with N, 2/3 N and ½ N rates, respectively. At the end of the second year experiment, N, 2/3 N and ½ N rates of 2,4-D + picloram resulted in 99.24%, 97.26% and 90.16% reduction in the shoot height of dwarf mesquite (Fig. 4.94). In a study conducted in Texas, Beck et al. (1975) stated that, 2,4,5-T plus picloram was clearly more effective than 2,4,5-T amine and 2,4,5-T ester against mesquite (*Prosopis velutina*) particularly when applied on mesquite plants before pod maturity.

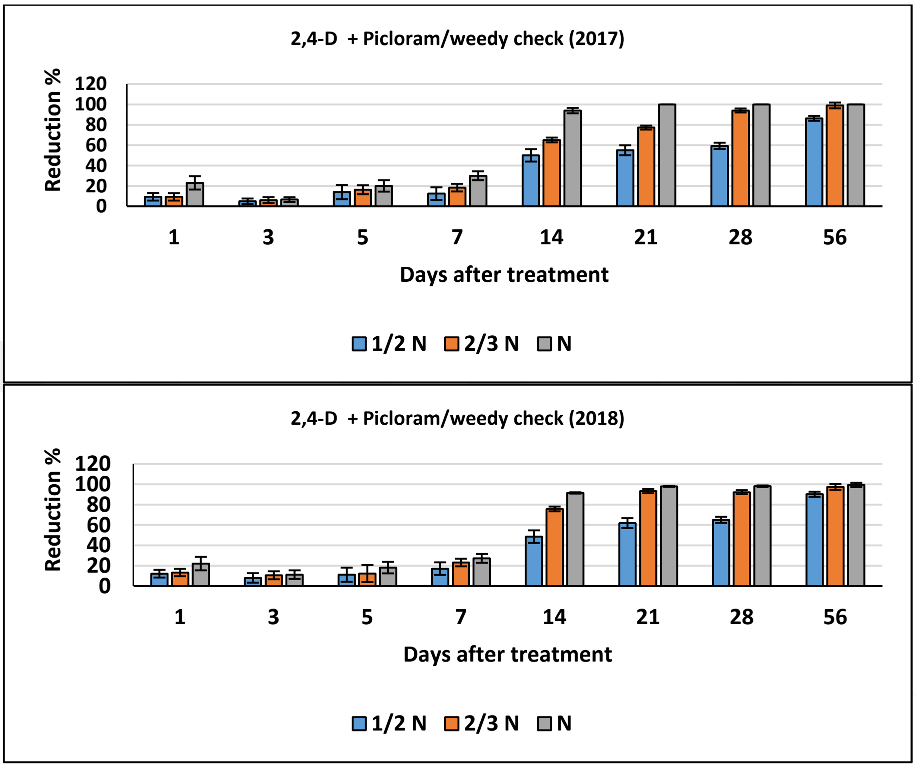


Figure 4.94. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], compared to the untreated weedy check as affected by application of 451.4 g/l 2,4-D triisopropylamine + 116.3 g/l picloram at three doses during two years experiment (2017-2018).

4.5.2.10. Effect of 2,4-D + Picloram Compared to the Weed-Free Check

Relative to plots where dwarf mesquite was kept free from other weed species, 2,4-D plus picloram caused a considerable (about 100%) reduction in the above-ground part of dwarf mesquite when applied at N or 2/3N rates. In the first experiment, half dose of herbicides led to 60, 80, 74 and 89.25 percent reduction during the 2nd, 3rd, 4th and 8th WAT, respectively. In the second year, the same rate led to 61.86%, 70.35%, 72.7% and 92.67% growth reduction during the second, third, fourth and eighth WAT, respectively. This premix has proven to be the most effective herbicide against dwarf mesquite (Fig. 4.95)

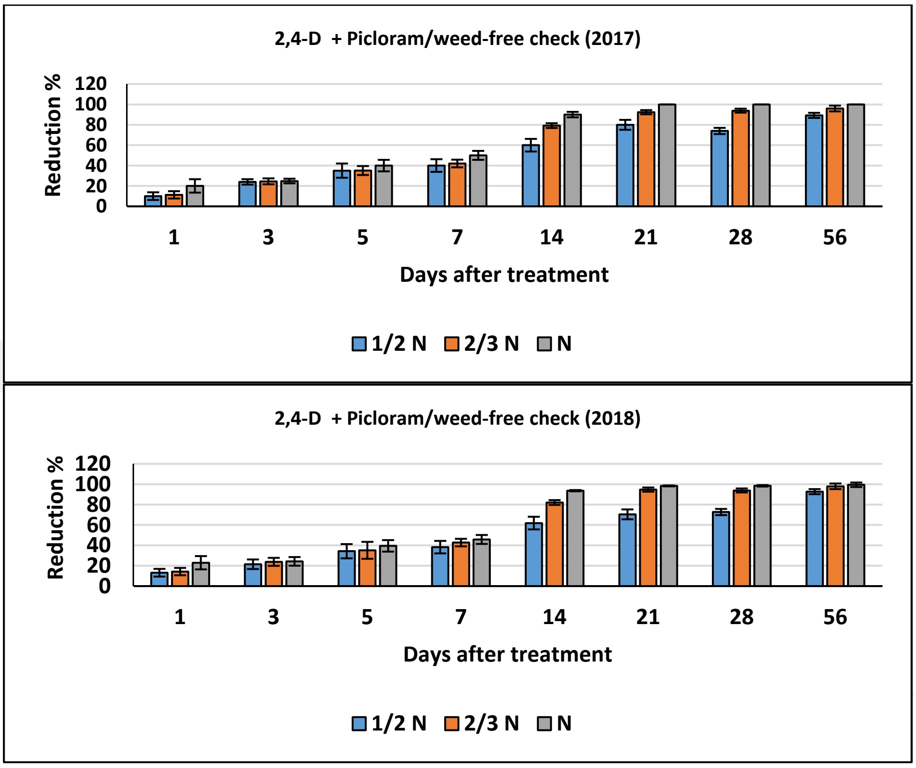


Figure 4.95. Percentage reduction in shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], compared to the untreated weed-free check as affected by application of 451.4 g/l 2,4-D tri-isopropylamine + 116.3 g/l picloram in three doses during two-years experiment (2017-2018).

4.5.2.11. Comparative Effect on Dwarf Mesquite (*P. farcta*) Growth

On the first day after treatment, *P. farcta* seedling showed no differences among different treatments. Even weedy and weed-free plots have recorded the same shoot length (Fig. 4.96).

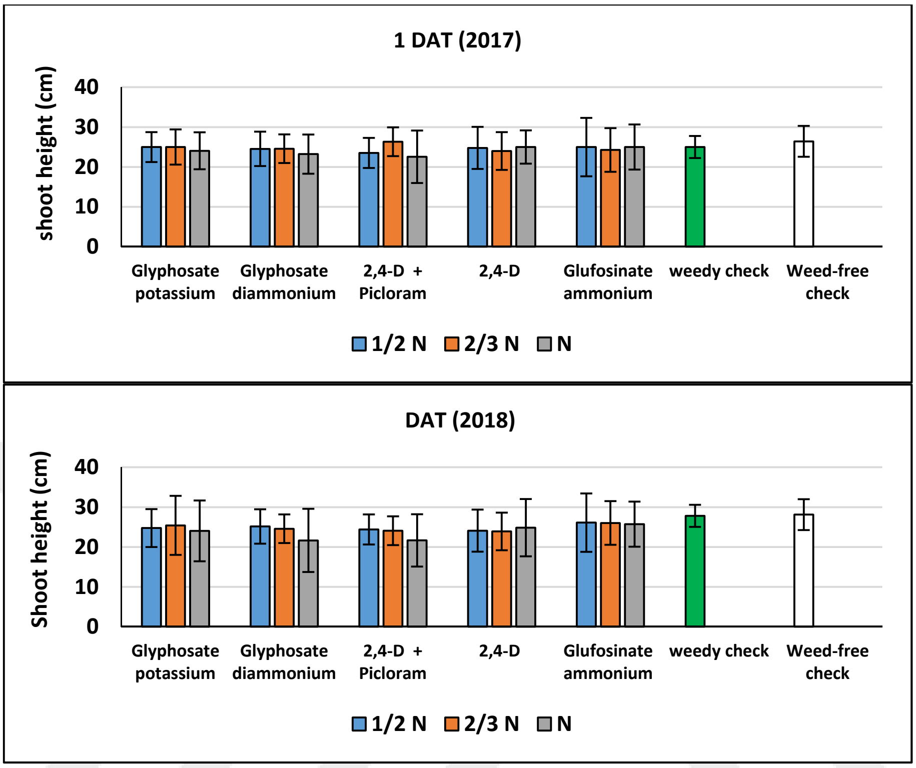


Figure 4.96. Effect of five herbicides applied on three doses on shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], on the first day after herbicide application during a two-year experiment (2017 and 2018).

Three days after herbicide applications, except for weed-free controls, no treatment has negatively affected the vertical growth of dwarf mesquite. Furthermore, no significant difference has been detected between the results obtained from the first year and those recorded in the second year, in terms of herbicide efficacy (Fig. 4.97).

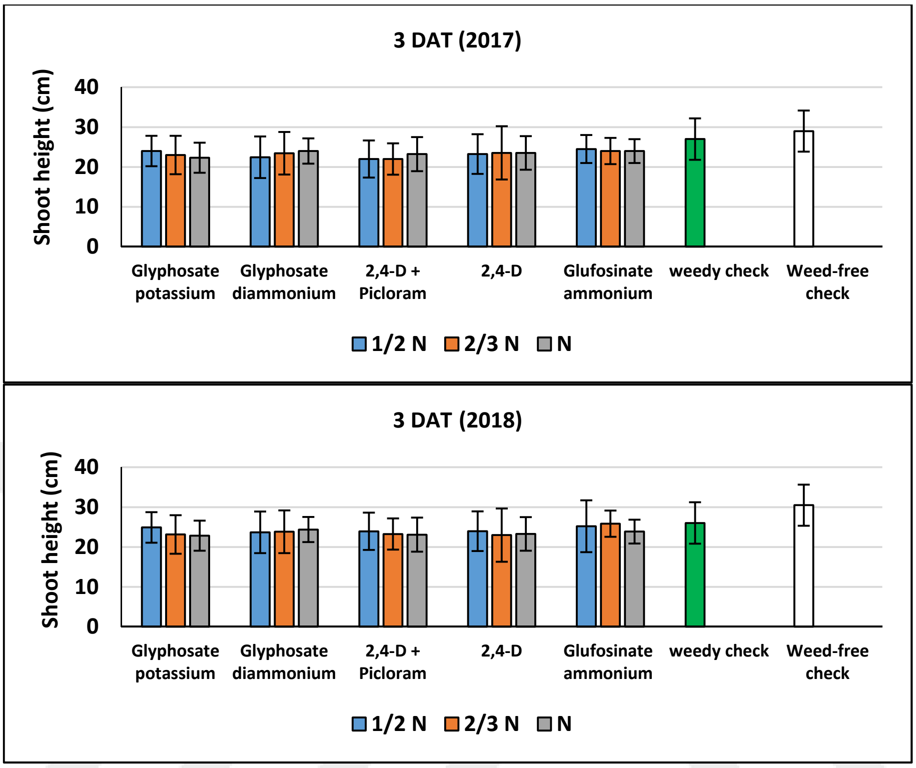


Figure 4.97. Effect of five herbicides applied on three doses on shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], on the third day after herbicideapplication during a two-year experiment (2017 and 2018).

For the two experiments, there was a statistically significant difference ($P<0.05$) between herbicide treatments and weed-free checks. However, no statistical difference ($P>0.05$) has been detected between herbicide treatments and untreated weedy controls (Fig. 4.98).

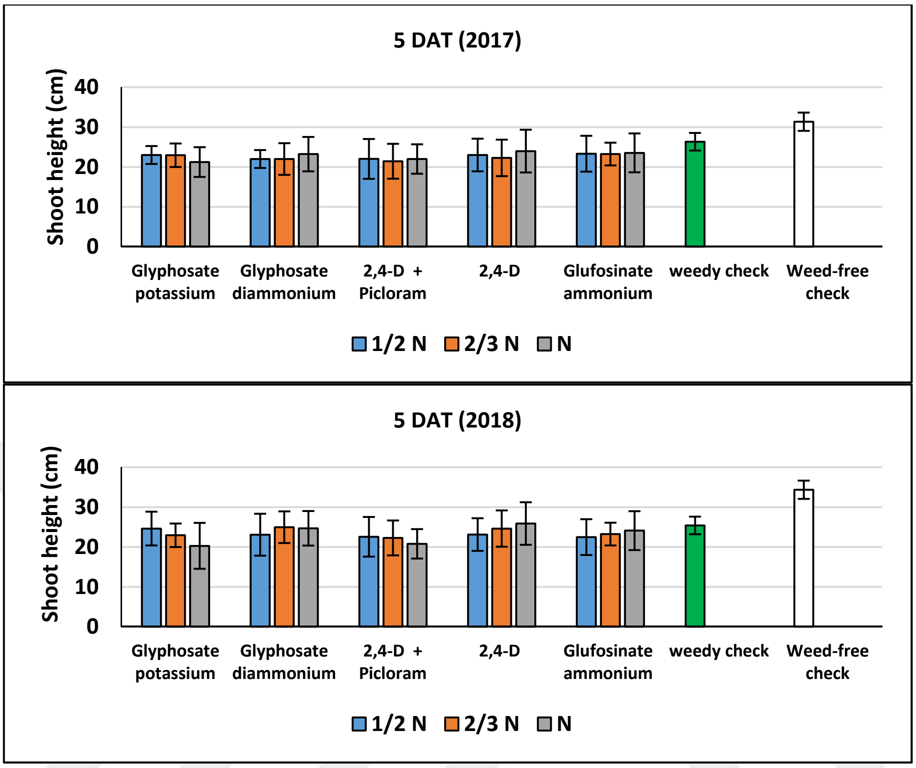


Figure 4.98. Effect of five herbicides applied on three doses on shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], on the fifth day after herbicide application during a two-year experiment (2017 and 2018).

Remarkable reduction in mesquite growth was recorded in all herbicide treatments, compared to both weedy and weed-free controls. For example, in 2017, glyphosate diammonium reduced the shoot height from 27 cm in the weedy check to approximately 20 cm at the three doses. In the other hand, within herbicides, no significant difference (P>0.05) between application rates was found (Fig. 4.99). Singh and Singh (2004) found that the application of glyphosate on twelve weed species caused less reduction in plant growth compared to trifloxysulfuron.

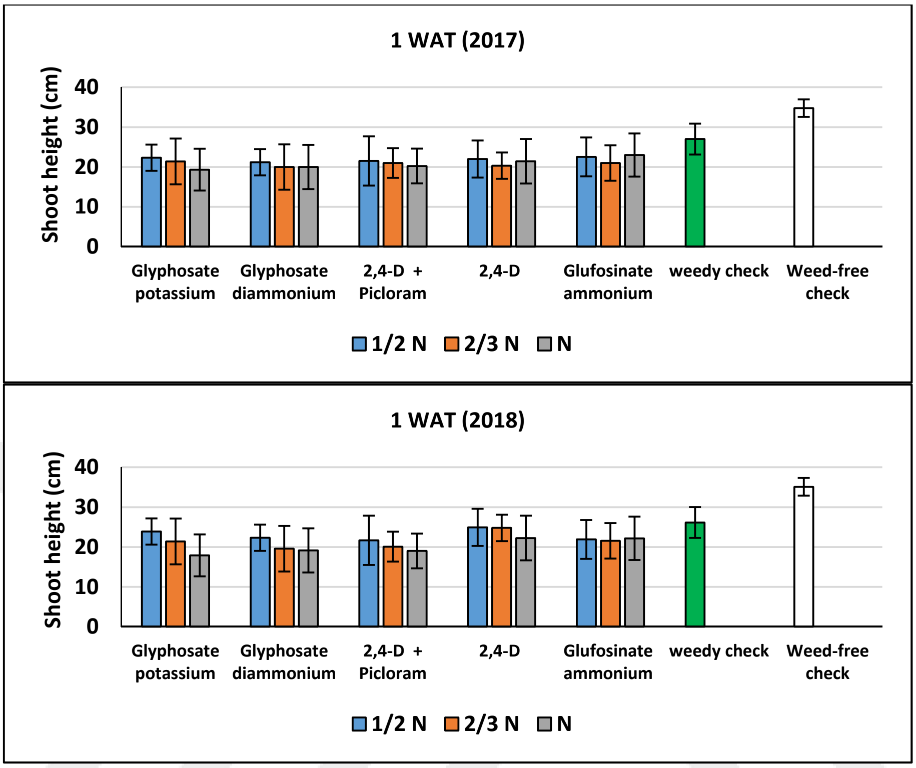


Figure 4.99. Effect of five herbicides applied on three doses on shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], on the first week after herbicide application during a two-year experiment (2017 and 2018).

In the second week of the first study, the highest effect on dwarf mesquite growth was caused by aerial application of 2,4-D plus picloram. In the first year-experiment, dwarf mesquite plants treated with 2,4-D plus picloram at N (5677 g a.i. ha^{-1}), 2/3 N (3784 g a.i. ha^{-1}) and ½ N (2838 g a.i. ha^{-1}) rates remained 7.32, 12.04 and 13 cm long while the untreated weedy and weed-free checks were 28.05 and 35.67 cm long, respectively. in the second-year experiment, application of N, 2/3 N and ½ N rates caused *P. farcta* shoots to remain 2.32, 6.6 and 14.03 cm long while weedy and weed-free checks was 27.26 and 36.77 cm long, respectively (Fig. 4.100). However, some herbicides, glyphosate-based formulations for instance, were effectively reduced plant height but they did not kill the plant. Bentivegna et al (2017) reported that the application of glyphosate on weeds at early and advanced growth stages was been effective enough to reduce plant shoot height but did not kill the plant.

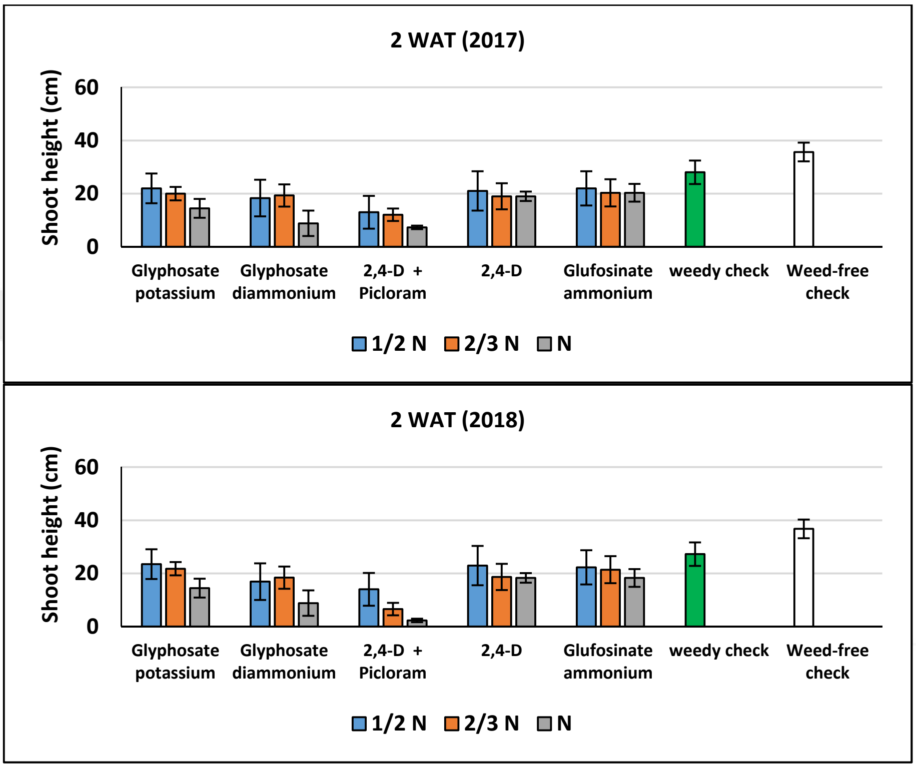


Figure 4.100. Effect of five herbicides applied on three doses on shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], on the second week after herbicide application during a two-year experiment (2017 and 2018).

During the third week of the experiment, growth of dwarf mesquite shoots treated with 2,4-D plus picloram was significantly reduced compared to the untreated weedy and weed-free check plots. Although the recommended dose has shown more reduction in plant height, statistically there were no differences among the different doses. Other herbicides were slightly varied in their overall effect on mesquite growth. In the same way, there were significant ($P<0.05$) differences in the shoot heights of weedy and weed-free plots (Fig. 4.101).

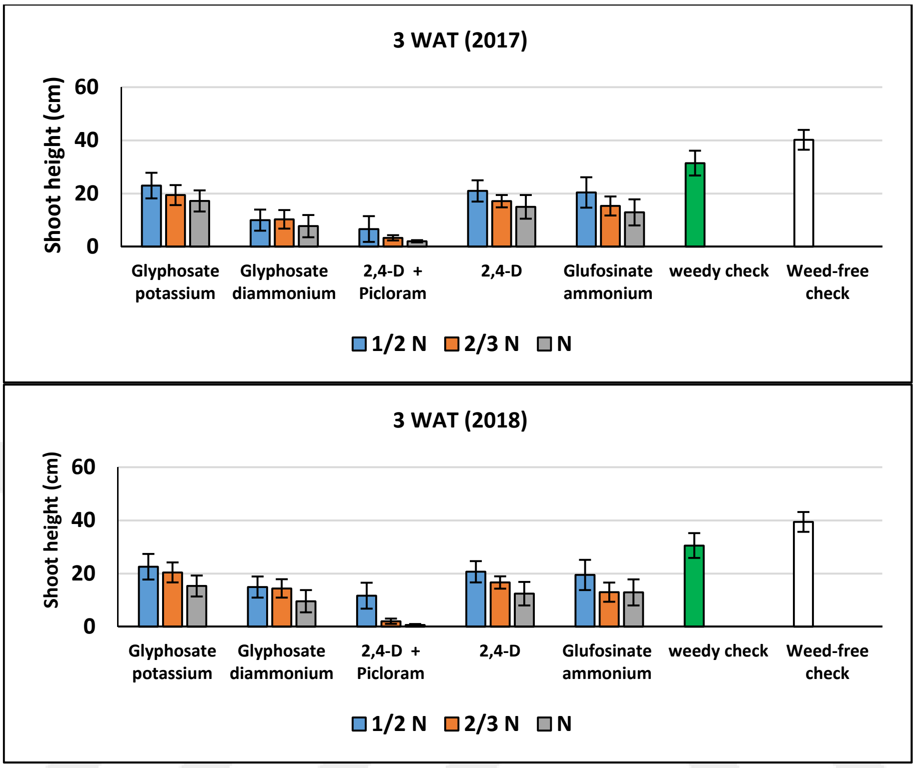


Figure 4.101. Effect of ve herbicides applied on three doses on shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], on the third week after herbicide application during a two-year experiment (2017 and 2018).

In the first month of herbicides application the effect of 2,4-D plus picloram remained the highest, while effectiveness of other herbicides began to decrease gradually as dwarf mesquite advanced in vegetative growth. Moreover, a parallel increase in the growth and development of the weedy and weed-free plants was observed throughout the experiments (Fig. 4.102).

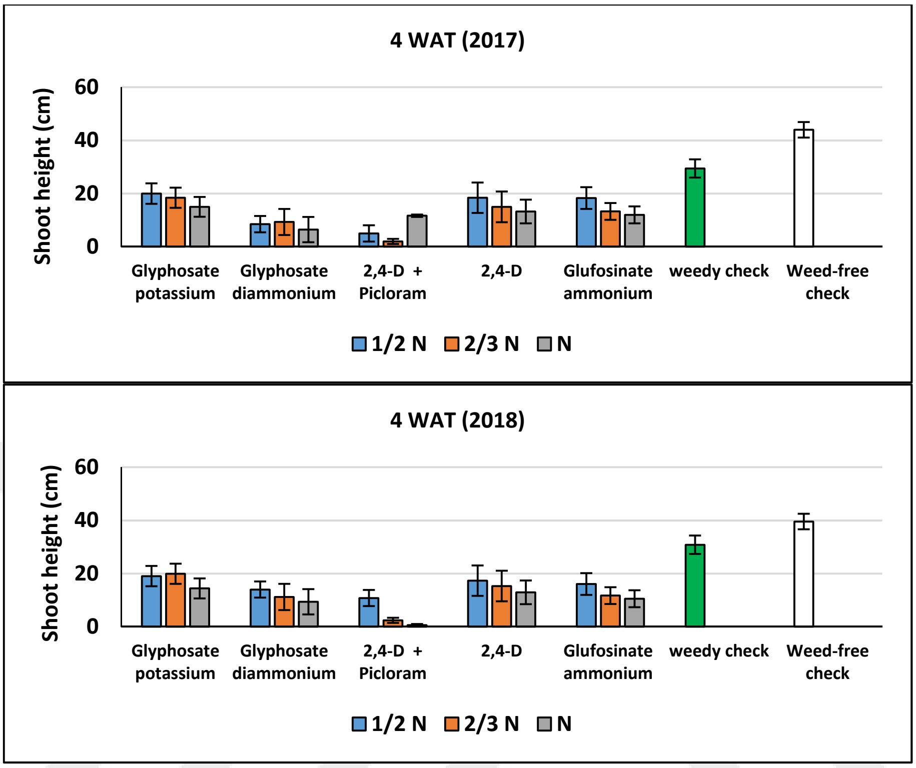


Figure 4.102. Effect of five herbicides applied on three doses on shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], on the forth week after herbicide application during a two-year experiment (2017 and 2018).

At the end of the two studies (2017 and 2018), no growth recover was recorded in dwarf mesquite plants treated with the premix herbicide, 2,4-D+picloram. In contrast, plants exposed to other herbicide treatments were partially or fully recovered from injury symptoms and recovery percentage was obviously greater in the plants treated with glyphosate diammonium, 2,4-D amine, glufosinate ammonium and glyphosate potassium, respectively (Fig. 4.103).

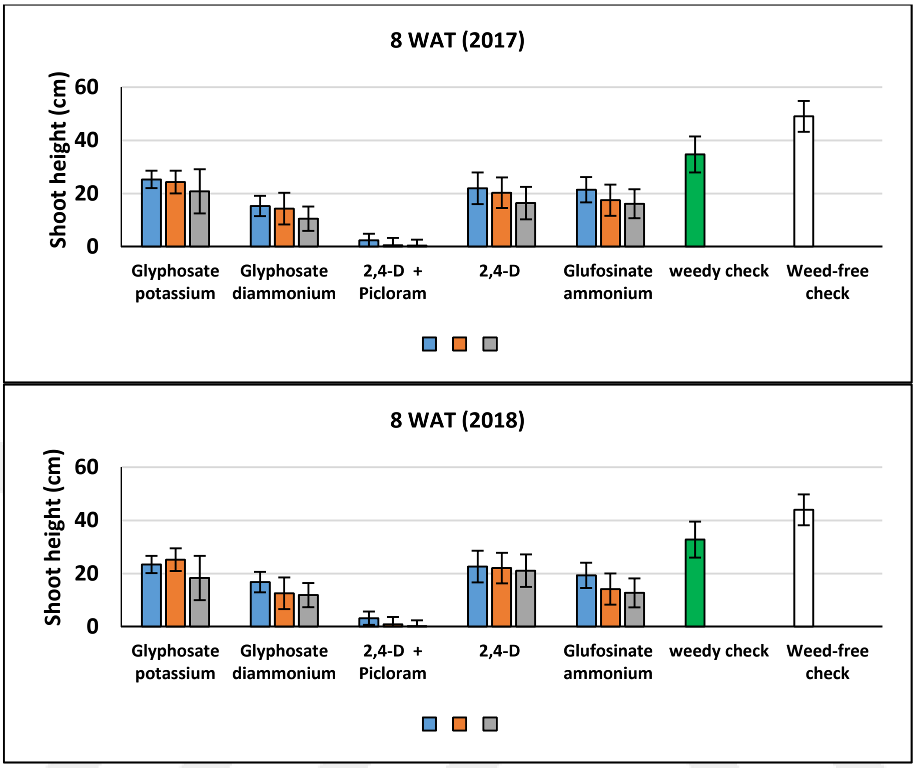


Figure 4.103. Effect of five herbicides applied on three doses on shoot height of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.], on the eighth week after herbicide application during a two-year experiment (2017 and 2018).

4.5.3. Effect of Herbicides on the Biomass of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.]

4.5.3.1. The Effect on Fresh Weight Compared to the Weedy Check

In the two-year experiment, among all the tested herbicides, only 2,4-D plus picloram has been effective enough to reduce the fresh weight of dwarf mesquite relative to untreated weedy checks. In the first study, application of 2,4-D plus picloram at N (5677 g a.i. ha^{-1}), 2/3 N (3784 g a.i. ha^{-1}) and ½ N (2838 g a.i. ha^{-1}) rates resulted in 91.32%, 90.05% and 72% reduction in fresh weight, respectively. Nearly the same results were obtained in the second year when this premix herbicide caused the highest reduction in dwarf mesquite fresh weight. Neal et al. (1985) was reported that the glyphosate uptake and translocation was significantly associated with the growth stage of the woody plants. This might be the reason on the poor control provided by glyphosate in this experiment. In contrast to Qasem, (2007), the lowest herbicidal effect was found in the 2,4-D amine treatments (Fig. 4.104).

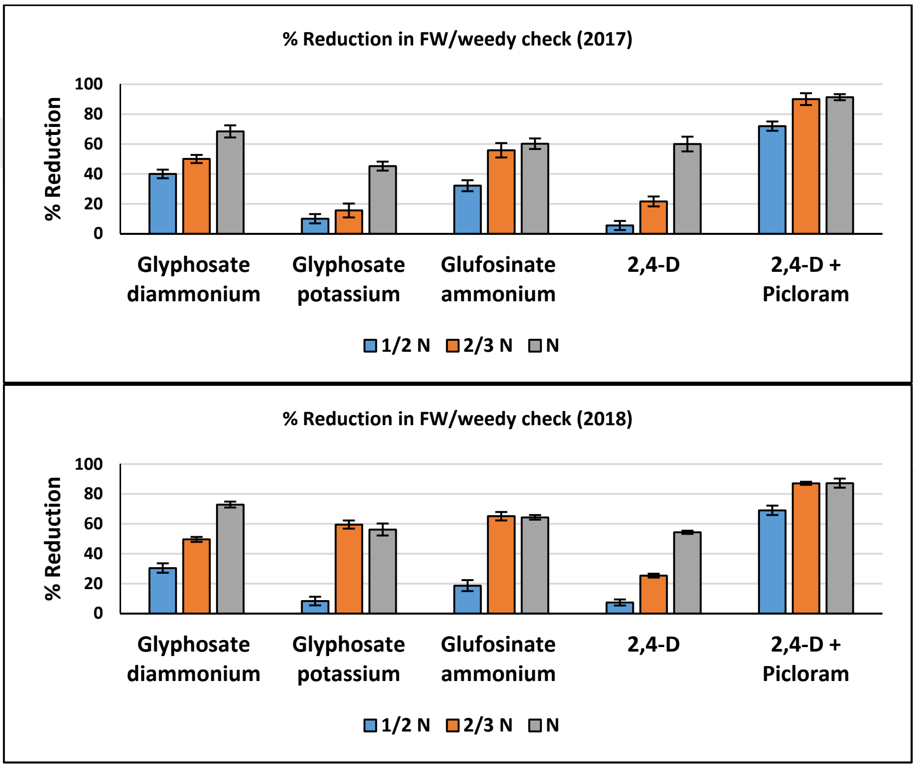


Figure 4.104. Percentage reduction in fresh weight of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], treated by five herbicides, three doses each, compared to untreated weedy check during two-year experiment (2017 and 2018).

4.5.3.2. The Effect on Fresh Weight Compared to the Weed-Free Check

Compared to untreated weed-free check, almost all herbicide treatments provided acceptable percentage reduction in plant fresh weight. In the first experiment, the recommended doses of glyphosate diammonium (93.28%), glyphosate potassium (83.36%), glufosinate ammonium (83.28%), 2,4-D amine (84.38%) and 2,4-D+picloram (94.74%) significantly reduced the fresh weight of dwarf mesquite, relative to the weed-free checks. Similarly, 93.37%, 86%, 80.23%, 75.32% and 72.29% reduction in dwarf mesquite fresh weight was provided by the application of two-third rates of 2,4-D plus picloram, glyphosate potassium, glufosinate ammonium, glyphosate di-ammonium and 2,4-D amine, respectively. However, the half doses, except for the 2,4-D+picloram (92%), caused approximately 60% reduction in the fresh weight of the dwarf mesquite. In 2018, the recommended doses of glyphosate diammonium (89.45%), glyphosate potassium (82.96%), glufosinate ammonium (86.11%), 2,4-D amine (82.25%) and 2,4-D+picloram (95.02%) caused considerable reduction in the fresh weight of dwarf mesquite. As suggested by Neal et al. (1985), the glyphosate seemed to be less effective in mature plants compared to the young ones. In the same way, the two-third doses of these herbicides were effective enough to affect the fresh weight, but, the half doses provided poor effect on the frech weights (Fig. 4.103).

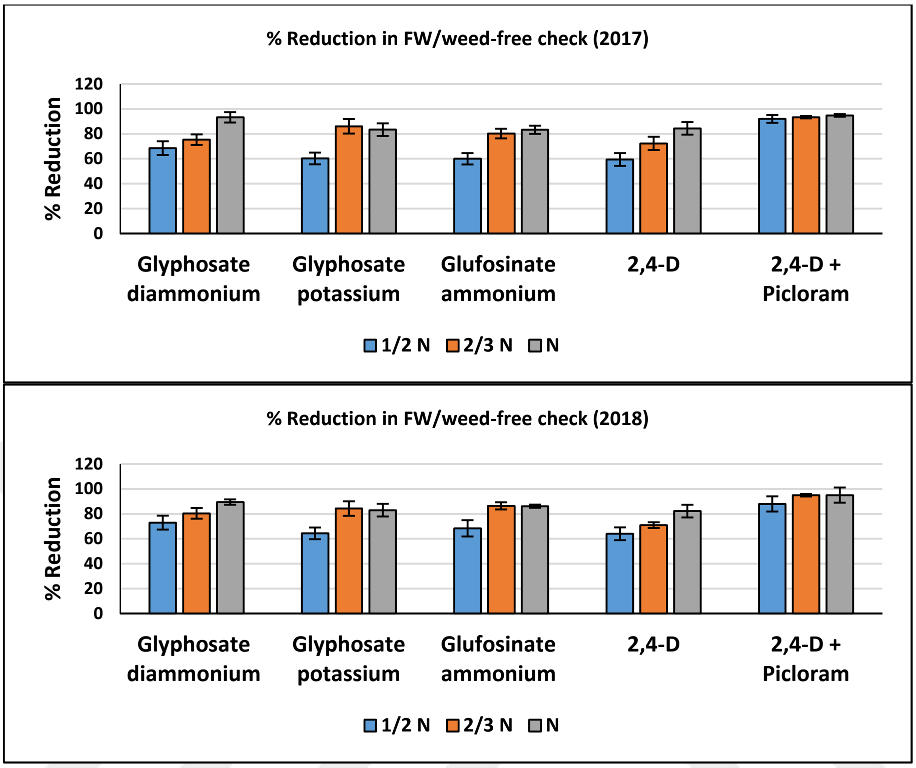


Figure 4.105. Percentage reduction in fresh weight of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.], treated by five herbicides, three doses each, compared to untreated weed-free check during two-year experiment (2017 and 2018).

4.5.3.3. The Effect on Dry Weight Compared to the Weedy Check

Herbicide application on dwarf mesquite led to relatively very low reduction in dry biomass compared to the untreated weedy plots. In the 2017 study, highest reduction was obtained in 2,4-D plus picloram with 85.51%, 70% and 70% decrease at N, 2/3 N and ½ N rates, respectively. Except for the recommended dose of glyphosate di-ammonium (58.29%), none of the tested herbicides has caused more than 30% reduction in the dry weight of *P. farcta* (Fig. 4.104). In the 2018 experiment, the recommended doses of glyphosate diammonium (60.21%), glyphosate potassium (3.48%), glufosinate ammonium (34.61%), 2,4-D amine (37.17%), and 2,4-D+picloram (87.08%), with the 2,4-D plus picloram causing the highest reduction in the dry weight at its recommended (87.08%) and two-third (84.71%) doses. In contrast, except the recommended dose of the glyphosate diammonium (60.21%), all the other herbicide doses caused resulted in less than 50% reduction in the dry weight of the dwarf mesquite. A research by Heitschmidt et al. (1986) has indicated that the application of 1:1 mixture of 2,4,5-T plus picloram on honey mesquite (*Prosopis glandulosa* var. *glandulosa*) resulted in mesquite density, height, and canopy of 248 plants/ha, 0.9 m, and 3.1%, respectively, compared to 963 plants/ha, 2.2 m and 34.6%, relatively, in untreated control plots.

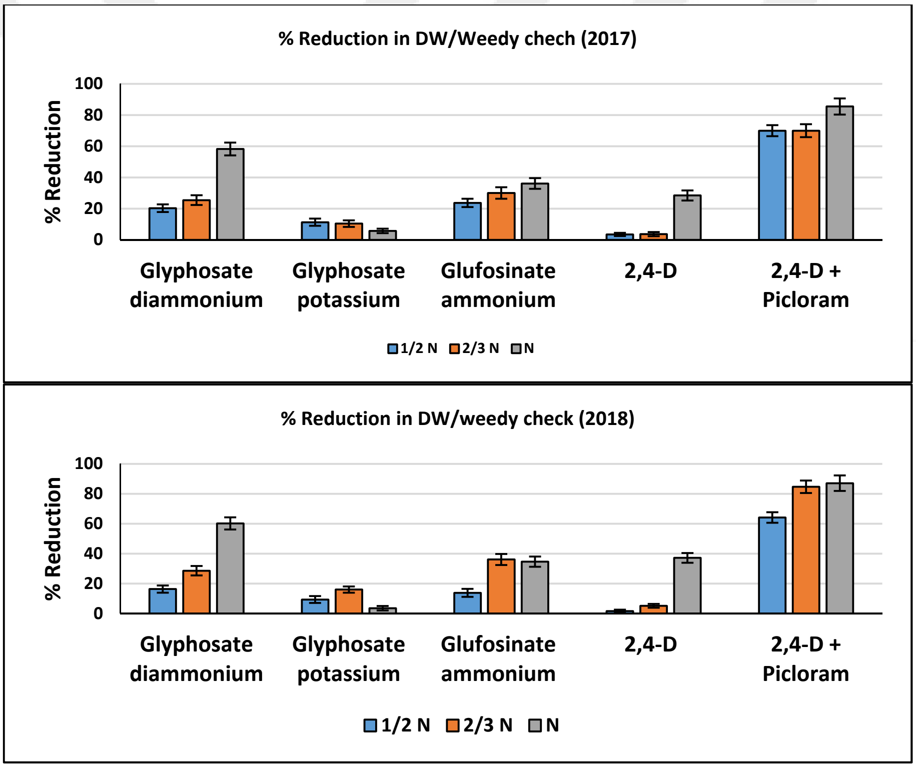


Figure 4.106. Percentage reduction in dry weight of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] treated by five herbicides, three doses each, compared to untreated weedy check during two-year experiment (2017 and 2018).

4.5.3.4. The Effect on Dry Weight Compared to the Weed-Free Check

Compared to the weed-free plots, the overall efficacy of the five herbicide treatments, was found to be sufficient for dwarf mesquite control. During the 2017 experiment, the recommended doses of the glyphosate diammonium (75.32%), glyphosate potassium (55.05%), glufosinate ammonium (70.25%), 2,4-D amine (68.41%) and 2,4-D plus picloram (97.03%) have shown to be effective treatments against *P. farcta*. The two-third and half doses of the glyphosate diammonium (70 and 56.92%), glyphosate potassium (55 and 53.2%), glufosinate ammonium (70.92 and 60.77%), 2,4-D amine (50 and 45.37%) and 2,4-D plus picloram (90 and 80.03%) provided considerable reduction in the dry weight. In 2018, 2,4-D+picloram (94.09%) and glyphosate diammonium (81.99%) proved to be the most effective herbicides at their recommended doses. However, the 2,4-D plus picloram was effective at the N, 2/3 N and ½ N doses, which resulted in 94.09, 93.04 and 83.71% reduction, respectively (Fig. 4.107).

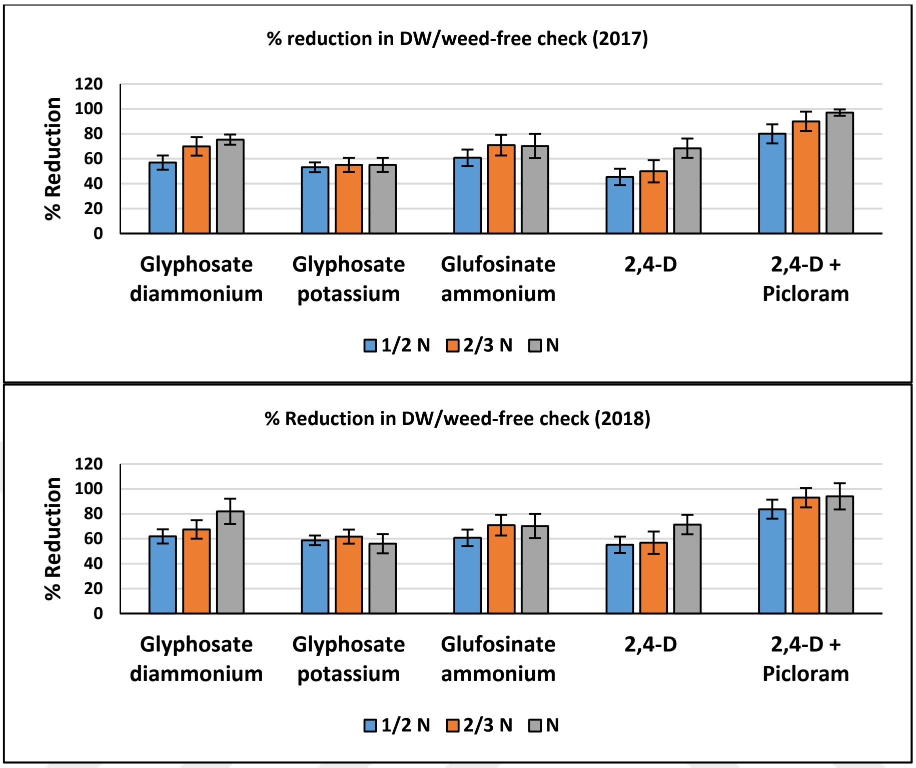


Figure 4.107. Percentage reduction in dry weight of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] treated with five herbicides at three doses, compared to untreated weed-free check during two-year experiment (2017 and 2018).

4.6. Phenological Development of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.]

According to the BBCH coding system, descriptive monitoring has revealed that bud and leaf folding was found to occur during April, when precipitation was up to 60 mm and maximum temperature reach 23°C in Adana Province. Stem growth, in terms of length and mass increment, started in May and reached the highest point by the end of May, when the lateral shoot has been at 90% of final length. However, during this period, reproductive development (flowering) began and continued until mid-July. In this period intensive appearance of pollinators were seen on dwarf mesquite flowers. Within a month after the end of the flowering stage, fruits were formed and reached its final sizes. Therefore, the fruits were fully ripened during the first week of September. Shoot growth was declined through October and the leaves began to drop off the plant in October and lasted until the mid of December (Table 4.1).

Table 4.1. Phenological Development Stages of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.]

Principal Growth Stage 0: Bud Development

BBCH	Description	Date
0 0	Dormancy: buds closed and covered by scales	-
0 1	Beginning of bud swelling	10 Apr
0 3	End of bud swelling	15 Apr
0 7	Beginning of bud breaking; shoot emergence	17 Apr
0 9	Buds show green tips	20 Apr

Principal Growth Stage 1: Leaf and Needle Development

BBCH	Description	Date
10	Green leaf tips 10 mm above the bud scales. Needle elongation	20 Apr
11	First leaves unfolded	23 Apr
1 5	More leaves unfolded, but not yet at full size. First leaves unfolded. Needle elongation, 50% developed	24 Apr
1 7	Most leaves unfolded on majority of the plant	24 Apr
1 9	Leaf expansion complete. Needle elongation complete	30 Apr

Principal Growth stage 3: Stem Elongation

BBCH	Description	Date
3 0	Beginning of stem elongation	30 Apr
3 1	Stem about 10% of final length	04 May
3 3	Stem about 30% of final length	06 May
3 5	Stem about 50% of final length	08 May
3.	Stages continuous….	During May
3 9	Stem about 90% of final length; cessation of stem growth.	26 May

Principal Growth Stage 5: Inflorescence Emergence

BBCH	Description	Date
5 1	Inflorescence or flower buds visible	10 May
5 5	First individual flowers visible but still closed	15 May
5 9	First flower petals visible (in forms with petals)	20 May

Principal Growth Stage 6: Flowering (main shoot)

BBCH	Description	Date
6 0	First flowers open	25 June
6 1	Beginning of flowering, 10% flowers open	30 June
6 2	20% of flowers open	03 July
6 3	30% of flowers open	04 July
6 4	40% of flowers open	10 July
6 5	50% of flowers open, full flowering: first petals fallen	12 July
6 7	Flowering finishing; majority of petals fallen or dry	14 July
6 9	End of flowering: fruit set visible. End of flowering	20 July

Principal Growth Stage 7: Fruit Development

BBCH	Description	Date
7 2	Fruit at 20% of final size	30 July
7 5	Fruit at 50% of final size	05 Aug
7 8	Fruit at 80% of final size	10 Aug
7 9	Fruit at final size	15 Aug

Principal Growth Stage 8: Fruit Ripening

BBCH	Description	Date
8 9	Fruits are fully ripe	04 Sep

Principal Growth Stage 9: Senescence, Beginning of Dormancy

BBCH	Description	Date
9 1	Shoot growth completed; foliage still green and terminal buds developed	01 Oct
9 2	Beginning of leaf discoloration	30 Oct
9 3	Beginning of leaf fall	15 Nov
9 5	50% of leaves has fallen	30 Nov
9 7	End of leaf fall	15 Dec

In the field conditions, the dwarf mesquite showed eight of the ten principal growth stages of the BBCH scale. The plant growth started with the bud development (stage 0) and ended with the senescence (stage 9). During the development of dwarf mesquite, the BBCH stage 2 (formation of side shoots) was not considered as the dwarf mesquite is a perennial shrub that sprouting from the side shoots of the previous year. Similarly, the BBCH stage 4 (development of harvestable vegetative plant parts or vegetatively propagated organs) was not recorded as it is not relevant to the mesquite plants. Pud development started in early April and continued until the end of the same month where the first leaf tips appeared. Most leaves of the dwarf mesquite plant were unfolded by the last week of April. Stem elongation and inflorescence emergence occurred during the first two weeks of May. Flowering was begun in June, where the first flower was opened in the last week of June and the flowering was ended and majority of petals has fallen in mid to late July. The fruit set occurred in mid July, reached the final size in early August and fully ripened during the first week of September. The senescence stage of the dwarf mesquite began slowly from the late October until reached its climax in December During this period the plants were observed to have their leaves fallen and the fruits remained dry on the plant (Fig. 4. 108). Bükün et al. (1995) studied the phenological of *P. farcta* and it was reported that the leaves of dwarf mesquite unfolded in April and flower buds were formed about 10 days later. The plant was begun to bloom in late May and early June, while the fruits were formed in late June and fully ripened in August.

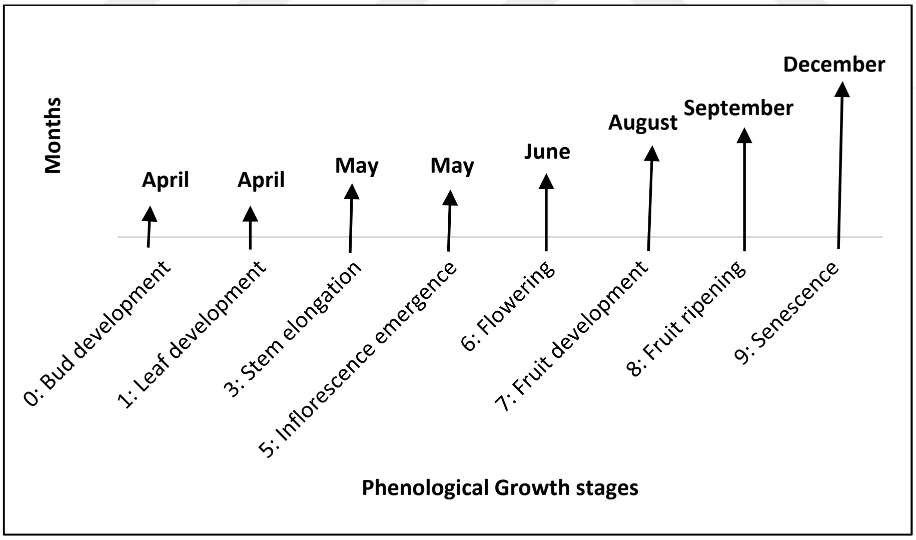


Figure 4.108. Growth stages of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.]

Since dwarf mesquite is a deciduous plant, it's adapted to survive in the dry regions by dropping its leaves during the winter months. In the early summer, plant stems turn green and leavas are usually develop from buds in the stem nudes. Buds are often swell, expand and form new leaves. Inflorescence was seen to develop immediately after leaf unfolding complete (Fig. 4.109).

Figure 4.109. Phenological development stages of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] (a = beginning of bud swelling; b = first leaf unfolded; c = most leaves unfolded; d = leaf expansion complete and inflorescence visible).

Approximately 50 small yellow flowers were observed on each inflorescene, but, only 2 -3 pods were eventually produced from each inflorescence. Pods remain on the plant for extremely long period of time. The main developmental growth stages of *P. farcta* has been shown below (Fig. 4.110).

Figure 4.110. The main phenological growth stages of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.] (a = 50% of flowers open and first petals were fell; b = fruits at 80% of final size; c = fruits final size; and d = fruits fully ripened).

4.7. Impact of Herbivorous Insects on Seed Production of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.]

Approximately 51% of the collected mesquite pods across the three sites were infested by insect herbivores, with a mean infestation rate of three exit holes per pod (Table 4.2).

Table 4.2. Infestation of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.] Pods by Insect Herbivores in Adana Province, Turkey

	Çatalan	Karaomerli	Çirişgediği
Damaged Pods (%)	49.10a	52.70a	50.90a
Healthy Pods (%)	50.90a	47.30a	49.10a

Means in the same column or row with the same letter are not significantly different at $p<0.05$.

At sites Çatalan, Karaomerli and Çirişgediği, a total of 6.6, 7.4 and 9.9 seeds per pod and 6.7, 6.5 and 8.7 seeds per pod were produced by infested and healthy pods, respectively, with seed production significantly higher at Çirişgediği ($p < 0.05$) (Fig. 4. 111).

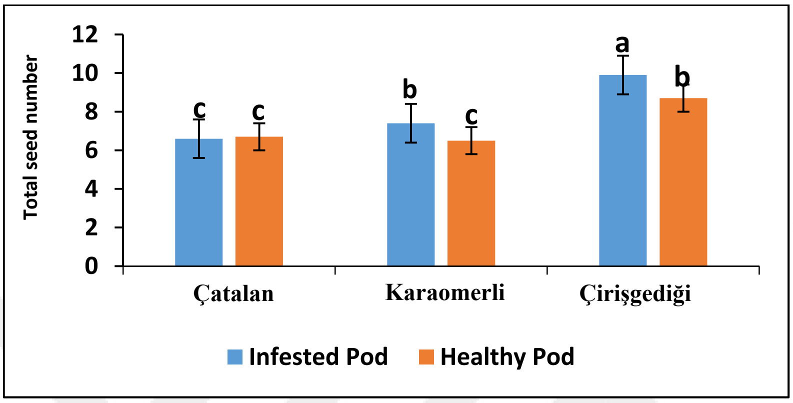


Figure 4.111. The total number of seeds (healthy, damaged and undeveloped) per damaged and healthy pods of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.]. Means labeled with the same letter are not significantly different ($p = 0.05$, LSD).

Significant differences in the mean number of healthy and damaged seeds per infested pod were observed among sites ($F = 15.35$, $p < 0.05$) (Fig. 4.112).

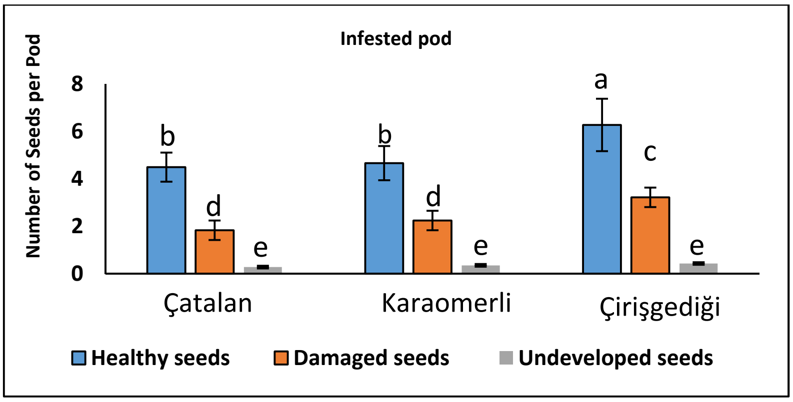


Figure 4.112. The mean number of healthy, damaged and undeveloped seeds per infested pod of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.]. Means labeled with the same letter are not significantly different at $p = 0.05$.

Among the three sites, the mean numbers of healthy and damaged seeds produced by the non-infested pods from Çirişgediği were significantly higher than for those at Çatalan and Karaomerli (p<0.05), whereas the mean number of healthy and damaged seeds/pod at sites Çatalan and Karaomerli were not significantly different (p>0.05) (Fig. 4.111).

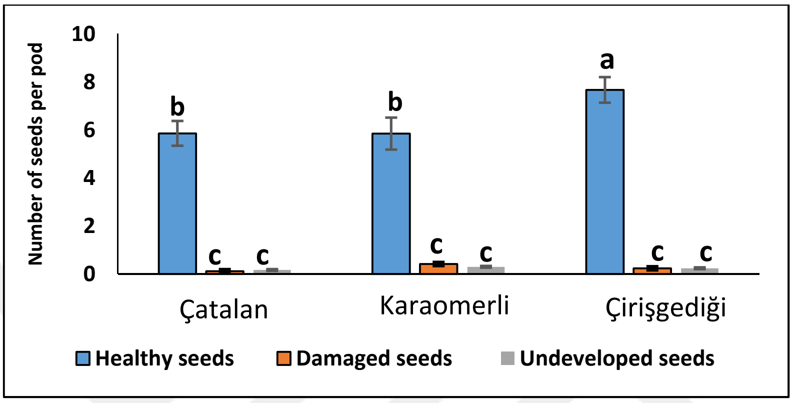


Figure 4.113. The mean number of healthy, damaged and undeveloped seeds per non-infested pod of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.]. Means labeled with the same letter are not significantly different at p = 0.05.

Significant differences were found among the three locations in terms of both pod length and width (p<0.05). However, the herbivorous insects didn't affect the length or width of the mesquite pods (Fig. 4.112).

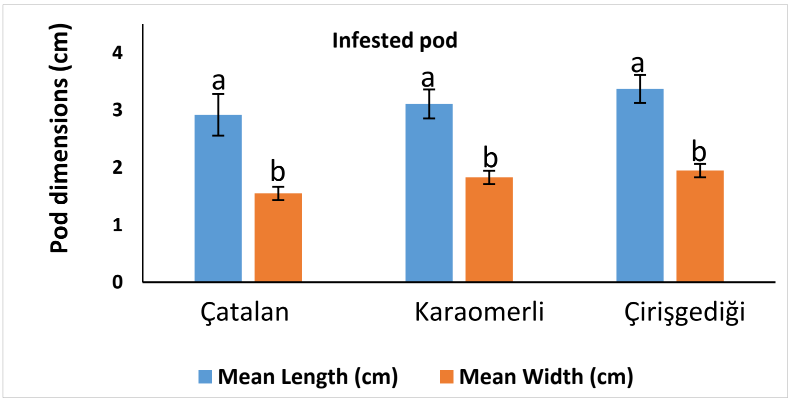


Figure 4.114. Mean length (cm) and width (cm) of infested pods of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.]. Means labeled with the same letter are not significantly different at p = 0.05.

Statistically significant ($F = 7.76$, $P < 0.05$) differences were also found among the study sites in terms of healthy pod size (length and width). The pods collected from the 3rd site were larger than those pods collected from the other locations (Figure 5). Significant differences were also found among the study sites in terms of the length and width of healthy pods ($F = 7.76$, $P <0.05$). There were no significant differences among the study sites in terms of the length and width of healthy pods ($F = 7.76$, $P > 0.05$). However, the pods collected from site Çirişgediği were wider than the pods collected from the other locations (Fig. 4.115).

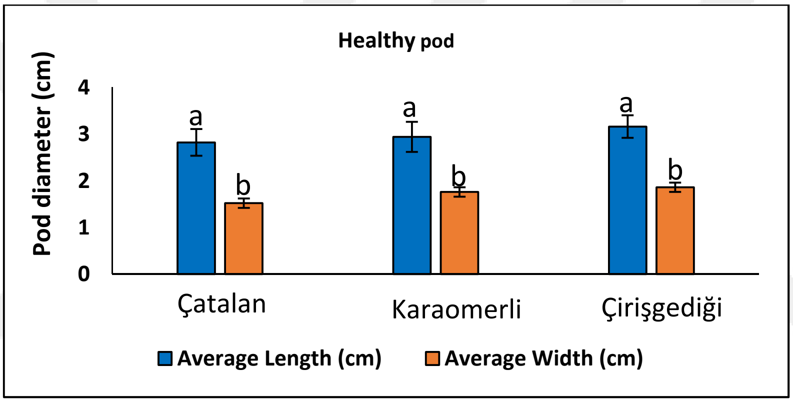


Figure 4.115. The mean length and width (cm) of healthy pods. Bars with the same letter indicate no significant difference at ($P < 0.05$).

In this study, the egg, larval and adult stages of four different insect families representing two different insect orders (Coleoptera and Hymenoptera) and mites (Acari) were collected inside the pods and seeds of the pest plant, dwarf mesquite. Members of the Family Bruchidae tended to feed principally inside the seeds. They, therefore, had a greater destructive impact on the potential for reproduction of dwarf mesquite which is why their identification was a priority. Five Bruchid species, *Caryedon palestinicus* Southgate (Pachymerinae), *Pachymerus lallemanti* Marseul (Pachymerinae), *Pseudopachymerus* sp. (Pachymerinae), *Spermophagus kuesteri* Schilsky (Pachymerinae) and *Bruchus atomarius* L. (Bruchinae) were identified. In addition, *Latheticus oryza* Waterhouse (Coleoptera: Tenebrionidae) was also among the identified species. Only four Bruchidae species and *Latheticus oryza* Waterhouse shown in (Fig. 4.114) with insect-damaged seeds.

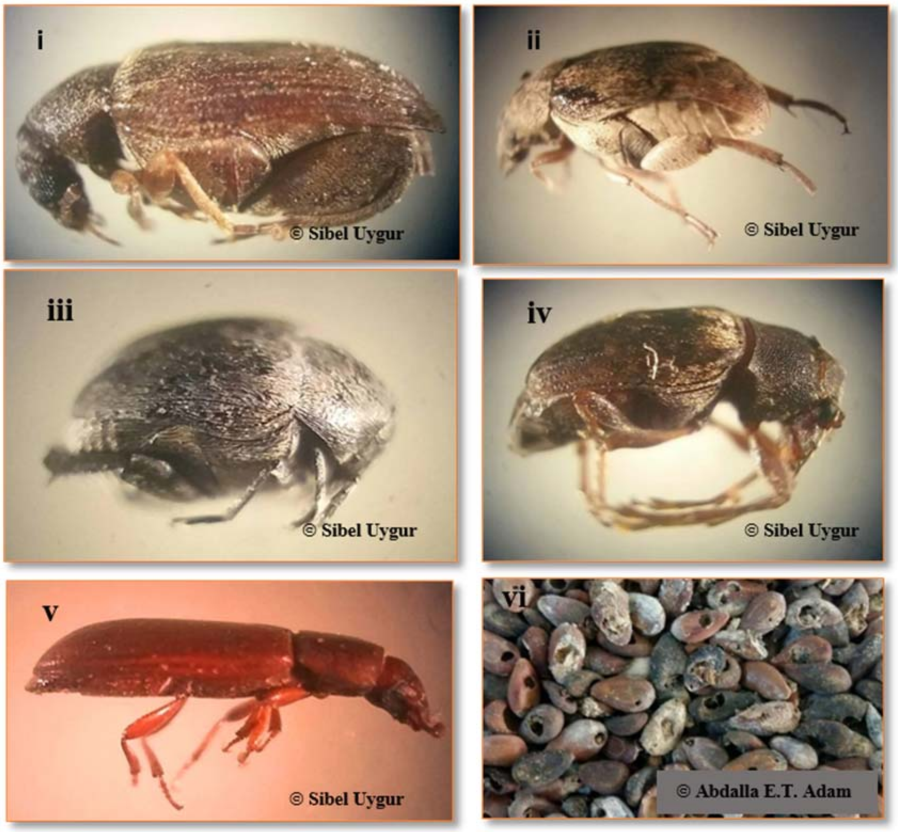


Figure 4.116. Micrographs of (i) *Caryedon palestinicus* Southgate, (ii) *Pachymerus lallemanti* Marseul, (iii) *Spermophagus Kuesteri* Schilsky, (iv) *Bruchus atomarius* L., (v) *Latheticus oryza* Waterhouse and (vi) damaged seeds of dwarf mesquite [*Prosopis farcta* (Banks & Sol.) F.J. Mac.].

5. CONCLUSIONS

The study results revealed that *P. juliflora* seeds have a higher germination percentage over a wider range of temperatures (15°C – 40°C) than *P. farcta* seeds (20°C – 40°C). However, both species seemed tolerant to elevated temperature, which make them more problematic in dry lands. Subsequently, rotating both crops and herbicides combined with a highly diversified farming system and introducing crops that require more irrigation water would probably lead to increased soil moisture which in turn decrease soil temperature and reduces the risk of mesquite invasion. However, farmers in some regions may fail to apply some weed-management oriented rotational farming systems as they affected by many factors other than weeds. For instance, in the market-driven production systems, practically certain crops cannot be cultivated although they might offer promising prospects for effective mesquite management. Mechanical scarification significantly enhanced seed germination of the two *Prosopis* species, indicating that conventional tillage and soil disturbance would significantly trigger mesquite seed germination. Therefore, to mitigate the effects of the world's worst offenders, *P. juloflora* and *P. farcta*, we suggest performing a reduced or no-till farming system as an alternative management strategy to minimize herbicide use, which has progressively become an indispensable tool for mesquite control worldwide.

Under greenhouse conditions, the recommended and two-thirds doses of all the tested herbicides were significantly superior over untreated control and successfully controlled the dwarf mesquite. Furthermore, 2,4-D plus picloram and glufosinate herbicides provided 100% control of dwarf mequite even when applied at half doses (1/2 N). Similarly, all the xamined herbicides provided successful control of common mesquite, especially with their recommended and two-third doses.

Table 5.1. The Control Percentages of Dwarf Mesquite [*Prosopis farcta* (Banks & Sol.) J.F. Mac.] as Affected by Application of Five Herbicides under Greenhouse Conditions (Average of Two-year Experiment)

Treatments	Effect of five herbicides on *P. farcta* under greenhouse conditions (% control)											
	2 WAT			**3 WAT**			**4 WAT**			**8 WAT**		
	½ N	**2/3 N**	**N**	**½ N**	**2/3 N**	**N**	**½ N**	**2/3 N**	**N**	**½ N**	**2/3 N**	**N**
Glyphosate diammonium	51	83	89	82	95	95	86	98	100	87	97	100
Glyphosate potassium	42	80	95	56	87	100	65	92	100	52	95	100
Glufosinate ammonium	68	80	86	84	91	94	63	94	99	73	94	100
2,4-D amine	53	61	67	66	78	94	83	94	98	89	91	93
2,4-D+picloram	93	99	99	100	100	100	100	100	100	100	100	100

Treatments	Effect of five herbicides on *P. farcta* under field conditions (% control)											
	2 WAT			**3 WAT**			**4 WAT**			**8 WAT**		
	½ N	**2/3 N**	**N**	**½ N**	**2/3 N**	**N**	**½ N**	**2/3 N**	**N**	**½ N**	**2/3 N**	**N**
Glyphosate diammonium	61	59	80	46	49	84	39	63	79	17	20	42
Glyphosate potassium	28	41	52	24	31	47	19	27	41	6	6	18
Glufosinate ammonium	77	79	80	60	64	71	52	59	69	30	37	48
2,4-D amine	42	72	74	31	60	63	26	53	56	13	24	45
2,4-D+picloram	81	92	97	81	94	98	83	97	100	76	92	100

Treatments	Effect of five herbicides on *P. juliflora* under greenhouse conditions (% control)											
	2 WAT			**3 WAT**			**4 WAT**			**8 WAT**		
	½ N	**2/3 N**	**N**	**½ N**	**2/3 N**	**N**	**½ N**	**2/3 N**	**N**	**½ N**	**2/3 N**	**N**
Glyphosate diammonium	38	87	92	43	91	94	82	98	100	91	100	100
Glyphosate potassium	63	93	99	68	92	99	95	100	100	83	100	100
Glufosinate ammonium	45	82	91	53	88	96	25	92	100	18	87	100
2,4-D amine	50	55	71	44	62	79	72	88	93	52	67	78
2,4-D+picloram	97	100	100	100	100	100	100	100	100	100	100	100

WAT: weeks after treatment, N: recommended dose.

Under field conditions, the greatest herbicidal effect on drawf mesquite biomass was observed in 2,4-D plus picloram and glyphosate di-ammonium treatments. However, all herbicides provided relatively poor control of dwarf mesquite in the field compared to that of greenhouse conditions. Except for 2,4-D plus picloram treatment, which caused over 90% control with its three rates, all other herbicides have shown to cause unsuccessful control of dwarf mesquite in the field condictions. This indicate that the two mesquite species are more susceptible to herbicides in early growth stages. This could be an advantageous for crop producers to prevent crop yield losses by controlling dwarf mesquite prior to the flowering stage. Although the premix herbicide, 2,4-D plus picloram, was the only herbicide showed complete (100%) control of *Prosopis* species with half of its recommended dose, the herbicide is recommended for use only in non-crop areas. Since glyphosate-based formulations have been recommended and widely used by farmers in Çukurova region, we suggest that application of glyphosate should be within herbicide rotation for controlling dwarf mesquite. The results highlight that early application of reduced herbicide doses, at least twice can play a substantial role in any strategic approach for dwarf mesquite control. Moreover, any mesquite control program should incorporate strategies that limit the spread of mesquite seeds and vegetative parts. Theses strategies may include preventing the dispersal of mesquite seeds by animals through restricting animal grazing in areas infested with mesquite plants. Additionally, effective manipulation of soil moisture by proper management of irrigation water at the field level would be particularly helpful for successful suppression of mesquite seedlings at early growth stages.

Phenology is an important functional plant trait that can contribute in many scientific disciplines from agriculture and climate change to biodiversity and public health. Implementation of phenological results obtained from this research is of a paramount importance for the community ecologists, weed scientists and entomologists to conduct an expanded and comprehensive work to achieve a qualitative shift in invasive weed management. For *P. farcta*, the plant phenology may be linked to many characteristics substantial for plant competition. For instance, leaf development was begun in the period when the plant starts to receive enough amount of light and nutrients whereas senescence began when the plant has been at a higher risk of herbivory. Similarly, the flowering period of dwarf mesquite was found to be extended from the 10th of May to the 20th of July and these may have a positive effect in terms of competition with other plants for pollinators. Therefore, flowering phenology is considered a key character in dwarf mesquite life. In contrast, the establishment of dwarf mesquite has been observed to start later in the growing season (April) and this is a negative characteristic for dwarf mesquite, because the species that establish earlier in the growing season should have the priority effect and benefit more by absorbing sources first from the soil. For effective and successful control of dwarf mesquite, farmers and farm managers are highly recommended to make their management decisions more early in the season.

Regarding the role that herbivorous insects have played in managing *P. farcta* populations, five insect species belonging to different families and orders were found inside both the pods and seeds of *P. farcta* in Adana province, Turkey. This wide range of natural enemies has been able to cause a considerable reduction in the number of viable seeds produced by dwarf mesquite unually. Approximately 51% of the investigated dwarf mesquite pods was found infested opening up the door for the researchers to study the effectiveness of the post-dispersal herbivory and to determine the post-dispersal fate of dwarf mesquite seeds in natural and agro-ecosystems. Bruchid species have been the most effective natural enemies because they feed directly on the seeds of *P. farcta,* in many cases leaving the seeds totally damaged or at least ungerminatable. Since the plants at Çirişgediği site generally set more seeds per pod, the seed quantity might be expected to lead to insect preference for larger fruits. Another reason is that the behavior of bruchid females may be driven by the need for sufficient food resources to ensure proper growth and development of their larvae. Therefore, high infestation rates resulting in more viable seed losses could be expected in this area. Sertkaya et al. (2005) reported that *Caryedon palestinicus* is not a promising biological agent against dwarf mesquite. However, our results suggest that native species, including *C. palestinicus*, appear to be potential biological control agents. A mass rearing and augmentative release program would probably greatly improve the management of this plant. Our investigations also showed that major damage to the seeds was done in the pods containing more than three larvae, indicating that the biological efficacy of these insects needs to be enhanced by improving their environmental tolerance, reproductive capacity and host-finding ability. Van Klinken and White (2014) reported that pre-dispersal predation is greater on seeds inside capsules after they fall to the ground. Therefore, on-plant seed predation and soil seed bank need to be investigated to estimate total seed predation on dwarf mesquite. Further research is also needed to determine if, and how, Bruchidae species affect the viability of dwarf mesquite seeds. This study reinforces the need for weed scientists and entomologists to cooperate for the improvement of our understanding of functional interactions between weeds and arthropods in agro-ecosystems. Research on the abundance of any natural enemies such as parasitoids and insect pathogens in the Adana region capable of attacking or negatively affecting the performance of these herbivores is also needed. Furthermore, an emphasis should be placed on the challenges and opportunities of using organisms other than insects as biological control agents for dwarf mesquite management.

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