SPATIAL GROWTH OF SORGHUM HALEPENSE (L.) PERS.*

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Summary. Small plants of Sorghum halepense (L.) Pers. were planted in the field and grown without competition from weeds and crops for 2½ years. The plant spread by means of subterranean rhizomes from which aerial shoots developed at increasing distances from the plant centre, and by tillering around these aerial shoots to form clumps. No preferential direction of expansion was detected and established patches developed an approximately circular shape.

Aerial growth stopped completely in the cold season. During the warm season the mean area increment amounted to 1-3 m²/month and was similar in both years of observations. After 2½ years of growth, patches had extended up to 3-4 m from the initial sprig and had a mean area of 17 m².

In the second summer of growth, shoot density reached 190/m² and mean seed production was 84 g, or 28 000 seeds per plant.

About 80% of rhizome dry weight was present in the upper 20 cm of soil and rhizomes did not penetrate deeper than 40 cm. About 80% of rhizome dry weight was present within 1 m radius from the plant centre.

Croissance dans l'espace de Sorghum halepense (L.) Pers.
Résumé. De petites plantes de sorgho d'Alep (Sorghum halepense (L.) Pers.) ont été plantées au champ et ont poussé pendant deux ans et demi en l'absence de toute compétition de la part de mauvaises herbes ou de plantes cultivées. Le sorgho d'Alep s'étend par l'intermédiaire de rhizomes qui portent des pousses aériennes se développant à des distances qui vont en augmentant à partir du centre de la plante, et par tallage de ces pousses aériennes pour former des touffes.

Il n'a pas été décelé de direction préférentielle de l'expansion et les taches formées par la plante étaient d'une forme approximativement circulaire.

La croissance de la partie aérienne fut complètement stoppée pendant la saison froide. Pendant la saison chaude, l'accroissement moyen de la surface s'éleva à 1,3 m²/mois et fut analogue pendant les deux années d'observations. Après deux ans et demi de croissance, les taches s'étaient étendues à 3,4 m du point initial et mesuraient en moyenne 17 m².

Dans le second été de croissance, la densité des tiges atteignit 190 au m² et le poids moyen de semences produites 84 g, soit 28 000 semences par plante.

Environ 80% (en poids sec) des rhizomes étaient présents dans les 20 premiers centimètres du sol et ils ne pénétrèrent pas au delà de 40 cm. Environ 80%, en poids sec, des rhizomes furent localisés dans un rayon de 1 m autour du centre de la plante.

Das räumliche Wachstum von Sorghum halepense (L.) Pers.

In der kalten Jahreszeit kam das Wachstum der oberirdischen Pflanzenteile völlig zum Stillstand. Während der warmen Jahreszeit belief sich der durchschnittliche Flächenzuwachs auf 1,3 m² je Monat. Der Zuwachs war in den beiden Untersuchungsjahren vergleichbar. Nach 2 1/2 Jahren hatten sich die Nester bis auf 3,4 m vom ursprünglichen Sproß ausgedehnt und bedeckten durchschnittlich 17 m².

Im zweiten Sommer stieg die Sproßdichte auf 190/m² an. Die durchschnittliche Samenproduktion betrug 84 g bzw. 28.000 Samen je Pflanze.

Ungefähr 80% des Rhizom-Trockengewichts befand sich in den oberen 20 cm des Bodens. Die Rhizome drangen nicht tiefer als 40 cm in den Boden ein. Etwa 80% des Rhizom-Trockengewichts war innerhalb eines Radius von 1 m der Pflanzenmitte.

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INTRODUCTION

*Sorghum halepense* (L.) Pers., a perennial grass of warm regions, is considered at present to be one of the ten most troublesome weeds of the world (Holm, 1969). The plant is native to the Eastern Mediterranean and in Israel many irrigated fields and orchards are severely infested by it. A measure of the spreading capacity of *S. halepense* is given by the history of its development in the United States: introduced late last century as a forage crop (johsongrass) it has now spread to become an increasingly serious weed problem over a large part of U.S.A. (McWhorter, 1971).

*S. halepense* is an erect grass which forms considerable numbers of aerial branches, i.e. tillers, many of which produce fertile seeds. It also forms, and is spread by, subterranean rhizomes (Oyer, Gries & Rogers, 1959; McWhorter, 1960, 1961; Horowitz, 1972a, b). This study investigated the mode and dynamics of the vegetative spread of *S. halepense* plants grown for more than 2 years without competition from other weeds or crops. The data were also compared with those of another perennial weed, *Cynodon dactylon* (L.) Pers. which had been grown under similar experimental conditions (Horowitz, 1972d).

MATERIALS AND METHODS

Thirty clonal sprigs of *S. halepense*, from a plant collected in a field in Newe Ya’ar, were grown until they had an aerial shoot of about 10 cm and rhizomes of about 5 cm length. They were then planted 6 m × 6 m apart in a clean field at Newe Ya’ar, on 23 June 1966. This field was adjacent to the experimental plots on which the spread of *C. dactylon* was investigated (Horowitz, 1972d), and both plots were maintained similarly. The field was sprinkler-irrigated during the warm season and the space between plants was kept free of weeds and of seedlings sprouting from seeds shed by *S. halepense*.

Observations on shoot and inflorescence production and on plant extension were made on eighteen plants during the first year, but towards the end of the second year this number had to be reduced to ten. The data given are means of eighteen plants, unless specified otherwise.

A discrete clump of one or more shoots is called a ‘tuft’, and is designated ‘central’, if it was the outgrowth from the initial sprig, or ‘eccentric’ if it appeared at a distance from it. Counts of the numbers of shoots or inflorescences comprised all culms present at the date of observation and thus includes culms recorded previously. Plant area and maximum extension were assessed in the manner detailed for *C. dactylon* (Horowitz, 1972d) until October 1968, when some adjacent swards intermixed. After the last observation soil samples were taken from five of the ten plants under continuous observation, and the amounts of rhizomes and roots present were examined as for *C. dactylon*.

RESULTS

Formation of shoots and inflorescences

The one-shoot sprigs rooted several days after planting and started branching after 2–3 weeks. The first eccentric shoot emerged about 1½ months after
planting and the numbers increased continuously during the following 3 months (Fig. 1b). There were, on the average, sixteen eccentric tufts per plant in November, at distances up to 115 cm from the plant centre.

Shoot formation was rapid in the central tuft, and five shoots had already formed 1 month after planting. At mid-August, the central tuft averaged twenty-five shoots, after which some shoots dried out and by mid-October, shoot numbers in the central tuft had dropped to fifteen.

Tiller formation was also very rapid in the eccentric tufts during the weeks following the emergence of the first eccentric shoot. The total shoot number present on all eccentric tufts averaged fourteen per plant in mid-August, forty-two in mid-September and sixty-four in mid-October. Active shoot formation continued on the eccentric tufts after it had stopped in the central tuft.

Growth almost ceased in November with the onset of the cool season. By this time, shoot numbers had reached their peak, averaging ninety per plant, though the best plant had formed 210 (Fig. 1c). Shoot number dropped sharply
after November, as no new shoots appeared and existing shoots desiccated and decayed, leaving an almost bare field at the end of the winter. In spring, with increase in temperature, new shoots appeared again, either at the site of previous tufts or where new vegetative points established from subterranean rhizomes which had remained alive through the winter. Shoot numbers increased extremely rapidly in the second spring, and in June the average shoot number per plant was 226 and the highest figure for an individual plant was 500. It was not possible to continue accurate counting after June, but an estimation based on shoot density of subsamples gave 1500 shoots per plant in November.

Total shoot numbers were significantly and positively correlated with plant area. In June 1967 the coefficient of correlation was $r = 0.61$ (for eighteen plants, significant at $P = 0.01$). Shoot density averaged $100/m^2$ at the end of the first season of growth and $190/m^2$ in June of the following season, when the patches appeared to be almost uniformly covered by shoots.

The first inflorescences were observed about 1½ months after planting and their numbers increased as shoot numbers increased (Fig. 1d). About one-third of the shoots formed in the first summer produced inflorescences with an average number of thirty-two per plant at the end of the first growth season. New inflorescences appeared on the spring shoots from May onwards, and the number of inflorescences rose rapidly during summer. The average number of inflorescences was 196 per plant at mid-June and 693 in November, out of a total shoot number of 1500. Mature seeds were harvested at several times during the summer of 1967. The total amount of seed averaged $84 \pm 13$ g/plant. One particularly well-developed plant bore 2000 inflorescences by November 1967 and produced 243 g of seed during that summer.

**Spreading of patches**

The expansion of *S. halepense* in the pioneer stage was often asymmetrical depending on the number and direction of growth of the first rhizomes. However, there was no preferential direction of rhizome growth established for all plants on the field, and the subsequent production of additional rhizomes and their branching soon gave a more symmetrical, approximately circular-shaped patch (Fig. 2).
Maximum radial extension and total plant area were repeatedly assessed from November 1966, when the perimeter of individual plants was sufficiently defined to allow the drawing of outline contour maps. Both forms of area assessment were highly correlated. For instance, in December 1966, the coefficient of correlation was \( r = 0.88 \); and in June 1967, \( r = 0.80 \) (for eighteen plants, significant at \( P = 0.01 \)).

The pattern of increase of plant area and its radial extension during 2.5 years are presented graphically in Fig. 3. The seasonal patterns of spreading are summarized in Table 1, in which the rate of expansion are averaged for four successive semesters. Two and a half years after planting the area of an individual plant ranged between 8 and 24 m\(^2\) for the ten plants under continuous observation. The mean final area was 17 m\(^2\), and the mean monthly increase in area was 0.6 m\(^2\). The rate of expansion, however, had marked seasonal variations. There was almost no growth in winter, when most aerial parts dried out, and the regrowth in early spring often started from an area smaller than that present in the previous autumn. The mean monthly area increment calculated for the May to October period was 1.3 m\(^2\), and exceeded 4 m\(^2\) for some individual plants in July–August. Although the area increments for summer 1967 and summer 1968 growth were similar, at about 8 m\(^2\), the extension increment in summer 1968 was only half that of summer 1967 (Table 1). This has also been noted for *Cynodon dactylon* (Horowitz, 1972d), which also expands its area concentrically. A continuously declining rate of radial extension is inevitable, unless the area of the plant increases in a geometric fashion.

After 2.5 years of growth, the maximum radial extension ranged between 2.1 and 4.4 m, with a mean value of 3.4 m. The rate of extension averaged
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20 cm/month during the warm season in 1967 and 10 cm/month in the same period of 1968.

Development of subterranean parts
The density and the amount of rhizomes and roots distributed beneath the patches after 2½ years of growth, are shown in Fig. 4. No rhizomes were found outside the perimeters of the patch and their distribution was similar along

<table>
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<tr>
<th>Table 1</th>
<th>Rate of expansion of <em>S. halepense</em> plants, summarized for 6-month periods (means of ten plants)</th>
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</thead>
<tbody>
<tr>
<td>Plant area</td>
<td></td>
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<tr>
<td>At end of period, m²</td>
<td>0.8</td>
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<tr>
<td>Increment for period, m²</td>
<td>–</td>
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<tr>
<td>Maximum extension from centre</td>
<td></td>
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<tr>
<td>At end of period, m</td>
<td>0.9</td>
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<tr>
<td>Increment for period, m</td>
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* ± Standard error.
† Area regressed in some plants.

Fig. 4. Distribution of subterranean dry weight in two layers beneath a plant of *S. halepense* after 2½ years of growth (means of four samples from five plants). At left, dry weight of rhizomes + roots (g per sample); at right, percentage of samples in which rhizomes were found.

the four perpendicular radii sampled, indicating a symmetrical development around the plant centre, which corresponds to the approximately symmetrical aerial growth at this time.

Root dry weight contributed about 10% of the total dry weight of subterranean parts. About 80% of the rhizome dry weight was present in the 0–20-cm soil layer and the remainder was present in the 20–40-cm layer. No rhizomes were found deeper than 40 cm in preliminary samplings, but roots penetrated
to deeper layers. About 80% of the subterranean dry weight was concentrated within 1 m radius of the plant centre, and almost all of the remainder was found between 1 and 2 m radius, with only a small number of rhizomes present at greater distances. The dry weight of rhizomes and roots present beneath the plant centre in the upper 20 cm amounted to about 700 g per m$^2$ of soil.

**DISCUSSION**

The above-ground expansion of *S. halepense* proceeds by tillering within existing tufts, which can increase their diameter by considerable amounts, and by the production of new shoots, which form on the rhizomes. In this experiment, the first shoots to appear away from the initial plant centre emerged 1$^{1/2}$ months after planting out. This agrees with earlier observations that small sprigs of *S. halepense* could tiller and form new rhizomes 6–8 weeks after planting in the warm season (Horowitz, 1972c). Once established, the plants spread rapidly during summer, particularly in the hot months of July–August, under these irrigated conditions (Fig. 3). McWhorter (1961) has reported a similar pattern from Mississippi; *S. halepense* plants growing from overwintered rhizomes produced 2 m of rhizomes after 1$^{1/2}$ months and up to 1 m of rhizomes per day, in August.

Growth and development virtually stopped from November to March, when the mean air-temperatures remained below 15°C. Earlier studies have confirmed that growth, and especially rhizome formation stopped below 15–20°C (Horowitz, 1972a and 1972b) and part of existing rhizomes can decay (McWhorter, 1961). Death of rhizomes of *S. halepense* requires temperatures of −3°C or lower (Hull, 1970; McWhorter, 1972) and temperatures in this range were never reached in our experiment. The extensive regrowth from rhizomes in spring confirmed that their exposure to low, but non-lethal temperatures did not impair subsequent growth at warmer temperatures (Hull, 1970). It is of interest to compare the pattern of spreading of *S. halepense* with that of *Cynodon dactylon*, another perennial grass, which in addition to a well developed rhizome system also has creeping stolons. While *S. halepense* forms dense tufts of tillers, *C. dactylon* produces a more open mat-like sward from the creeping stolons which rapidly cover the soil surface and root and branch at the nodes (Horowitz, 1972c). This difference in pattern of growth probably constituted an advantage in colonization and resulted in a greater expansion rate in *C. dactylon* than in *S. halepense* when both were grown under similar experimental conditions. For example, the mean monthly area increase in the warm season was 1.3 m$^2$ for *S. halepense* (Table 1) and 1.6 m$^2$ for *C. dactylon* (Horowitz, 1972d) and after 2$^{1/2}$ years of undisturbed growth their mean plant area was 17 m$^2$ and 25 m$^2$, respectively. Established patches of both species spread centrifugally, tending towards a circular shape but they had a fairly uniform distribution of shoots rather than the zonation recorded in *Spartina townsendii* (H. & J. Groves) and some other perennial grasses, which enlarge by concentric rings differing in shoot density (Caldwell, 1957).

Rhizomes of *S. halepense* (Fig. 4) like those of *C. dactylon* (Horowitz, 1972d) were mostly concentrated in the upper 20 cm of soil. With horizontal extension
averaging 3.4 m during 2.5 years of growth in *S. halepense*, the absence of rhizomes below 40 cm suggests an edaphic barrier. These experiments were all carried out in a heavy clay soil, and it is possible that compaction and aeration below 40 cm restricts the penetration of rhizomes (Andrews, 1940; Palmer, 1958). McWhorter (1972) reported that rhizome production in *S. halepense* was less, and at shallower depths in a clay soil than in a sandy loam, and that shoots from rhizome fragments emerged better in the sandy loam than in the clay soil.

The dry weight of subterranean parts present in the 0–20 cm soil layer below the plant centre of *S. halepense* after 2.5 years of growth was about 0.7 kg per m² of soil, which is similar to the dry matter accumulated beneath established patches of *C. dactylon*, about 0.8 kg/m² (Horowitz, 1972d). It has been shown (Friedman & Horowitz, 1970; Horowitz & Friedman, 1971) that dead residues of both species decaying in soil were capable of inhibiting the germination and early growth of barley, mustard and wheat over a period of several months. Residues of *S. halepense* were generally rather more phytotoxic than those of *C. dactylon*. In a field previously infested by *S. halepense*, the establishment of certain cultivated species can thus be affected even after the weed had been killed, due to the presence of decaying rhizomes in the topsoil.

The mean seed production during summer was 84 g per plant and since the mean thousand-kernel weight was 3 g, one plant produced, on the average, 28 000 seeds. It has been noted that one particularly well-developed plant produced 243 g of seed. McWhorter (1960) recorded 676 g of seeds from a plant of *S. halepense* grown on soil of high fertility. Since the seeds are generally fertile they add another dimension to the expansion of this weed and are probably a major source of dissemination, which was not examined in these studies in which germinating seedlings were pulled out.

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**REFERENCES**


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