THE GROWTH CURVE OF SORGHUM [1]

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INTRODUCTION

Growers and investigators of sorghum (*Sorghum vulgare* Pers.) generally have observed the small size of seedlings and the relatively slow early growth of the plants, as compared with those of corn, even when grown under optimum conditions. Measurements of the growth of sorghum plants at some stages doubtless have been made previously, but curves showing the trend of this slow early growth have not been found in the literature. In 1930, N. V. Kanitkar, then soil physicist of the Poona Agricultural College, Poona, India, while visiting the United States, showed the junior writer an unpublished growth curve of sorghum based upon data he had obtained in India. This curve was of the unbalanced sigmoid type, having a long gradual slope during the first several weeks of the period, that depicted strikingly the slow early growth and rapid later growth of sorghums. It seemed desirable to the writers to investigate this problem in the United States and if possible to determine the cause of this unbalanced trend in growth rate. The experiments were conducted by the senior writer.

Sorghums are of tropical origin and usually grow slowly at the cool temperatures that frequently occur after relatively early planting in the Northern States. The sorghums in the experiments reported here, however, were planted in June and July under conditions of high temperature and irrigation in southern Arizona, which favored rapid germination and early growth. Thus unfavorable environmental conditions that might have retarded early growth were largely eliminated from consideration as a causal factor in the growth trend.

METHODS

The experiments were conducted at the University Farm, Tucson, Ariz., under irrigation, during the 4-year period 1931–34 and in 1936. Two grain sorghum varieties, Dwarf hegari and Double Dwarf Yellow milo, were planted on two dates in each of the first 4 years. The average date for the first planting was June 18 and for the second planting July 22. Soon after the plants were well up they were thinned to a single plant every 8 to 10 inches. The plants of both varieties produced tillers that developed about as well as the main stalks. Plants were harvested at 4-day intervals starting soon after the plants were up and ending when maturity was reached. The plants were cut as close to the ground as possible and a minimum of 10 plants was harvested at each sampling. The number of stalks (in-

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cluding tiller stalks) was counted in each sample, and all weights were computed to weight per stalk. The harvested plants were weighed at intervals until they had reached a constant air-dry weight. The heads, if any, were then removed and threshed, and weights of the heads and seed were obtained.

RESULTS

RATE OF GROWTH IN SORGHUMS

The increase in weight per stalk, including the heads, seeds, and leaves, of Dwarf hegari and Double Dwarf Yellow milo planted on two dates is shown in figure 1. The curves were calculated by the formula suggested by Robertson,[3] i. e., $\text{Log}\frac{x}{a-x}=K(t-t_1)$, where x equals the weight attained in time t; a is the total growth attained during the cycle; K is a constant, the magnitude of which determines the slope of the curve; and t_1 is the time at which the growth is one-half completed; or where x equals $1/2a$. It will be observed that the early growth of both varieties was very slow. This was especially true in the June 18 planting. It was not until 54 days after planting that a weight per stalk of over 10 g was obtained in Dwarf hegari. This period constitutes roughly one-half of the number of days between planting and maturity. The early growth of Double Dwarf Yellow milo was slightly greater than that of Dwarf hegari until about 58 days after planting. From then until maturity the weight per stalk of Dwarf hegari increased more rapidly than in the shorter variety Double Dwarf Yellow milo. The weight per stalk 54 days after planting represented 10 percent of the weight at maturity of Dwarf hegari and 14 percent of Double Dwarf Yellow milo.

A theoretical[4] symmetrical sigmoid (S-shaped) curve of growth, typical of many plant species, also is shown in figure 1. This curve is superimposed upon the weights of the Dwarf hegari planted on June 18. It will be observed that the curve of actual dry-weight increase of Dwarf hegari was below that of the theoretical curve at all stages of development until maturity was reached. At maturity, of course, the two curves coincide.

The growth curves of sorghum show a delayed but more abrupt upward trend, with the upper and lower ends asymmetrical in contrast to the symmetrical theoretical curve. The difference may be explained by the small size of the sorghum seedling relative to that of the mature plant, which necessitates the lapse of considerable time before the operation of the so-called "compound-interest" principle can produce large increases in weight.

When the two varieties were planted on July 22 there was a more rapid increase in early growth and a lower weight at maturity than when they were planted on June 18. This rapid early growth might be attributed to slightly higher temperatures at planting time in the July 22 planting. The mean temperatures at Tucson for June, July, and August from 1931 to 1934 were 79.5°, 87.6°, and 84.4° F., respectively. When the varieties were planted on June 18 maturity was reached the first week in October, but when planted on July 22

[3] ROBERTSON, T. BRAILSFORD. THE CHEMICAL BASIS OF GROWTH AND SENESCENCE. 389 pp., illus. Philadelphia and London. 1923.

[4] RABER, ORAN. PRINCIPLES OF PLANT PHYSIOLOGY. 377 pp., illus. New York. 1928.

the varieties were not mature until the last week in October. The lower mean temperatures and shorter days during part of the growing period of the July plantings may have hastened heading and restricted

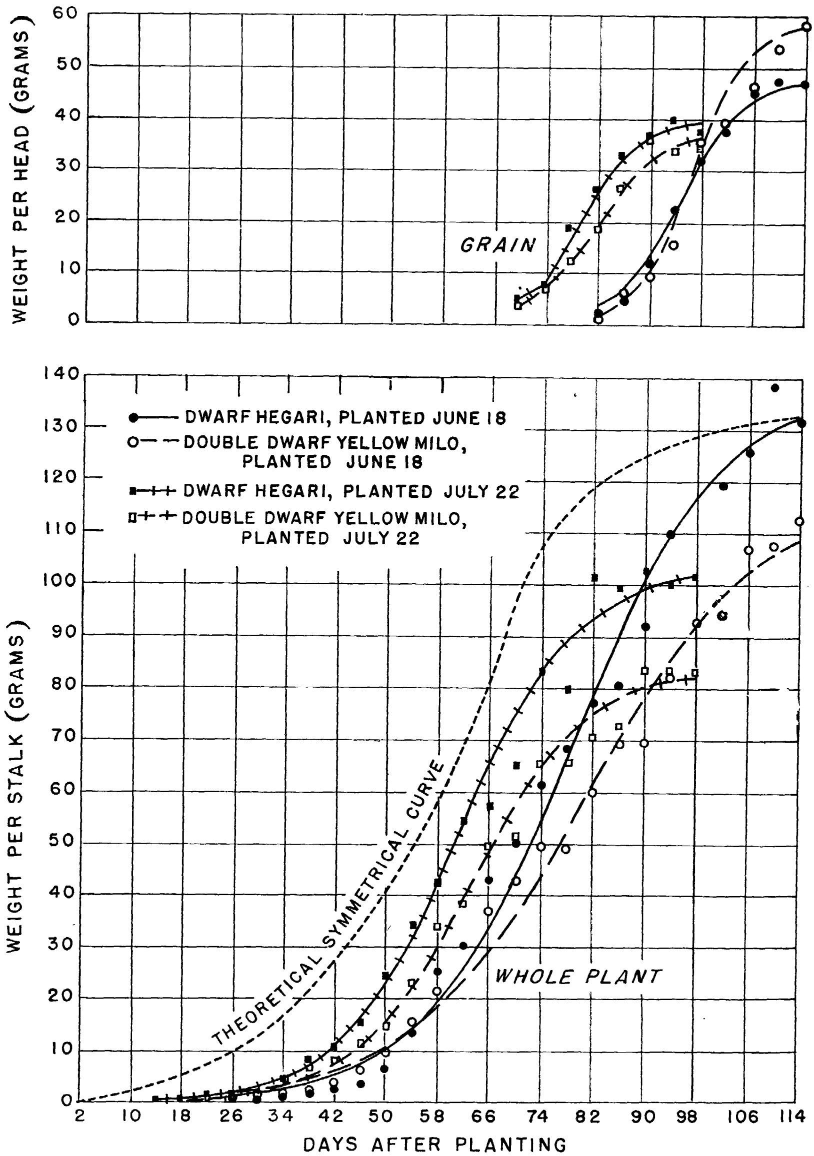

FIGURE 1.—Total air-dry weight per stalk and weight of grain per head of Dwarf hegari and Double Dwarf Yellow milo planted on two dates at Tucson, Ariz., 1931–34. The dots and circles represent the actual weights, and the lines the fitted curves.

vegetative growth, although the temperatures were sufficiently high during October to prevent delay in ripening.

The increase in seed weight per stalk of Dwarf hegari and Double Dwarf Yellow milo in the June 18 and July 22 plantings also is shown in figure 1. The poor fit in the curve for seed weight of Double Dwarf Yellow milo planted in June is due to damage by birds. However, both varieties yielded more in the June than in the July planting. In the June planting the seed yield of Double Dwarf Yellow milo was higher, but Dwarf hegari led in the July planting. The decreases as a result of later planting in weight per stalk and seed weight per head were 23 percent and 19 percent, respectively, in Dwarf hegari, and 26 percent and 41 percent in Double Dwarf Yellow milo. The Dwarf hegari evidently was better suited to late planting than Double Dwarf Yellow milo.

SEED SIZE AND EARLY GROWTH

In numerous experiments with sorghum seedlings, the junior writer has observed that varieties with large seeds produce larger seedlings and appear to grow more rapidly in the early stages than small-seeded varieties. It seemed that this apparent relationship between the size of seed and early plant growth might explain the growth trends just presented.

Mature stalks of some sorghum varieties often weigh nearly as much as mature cornstalks, although the seeds of grain sorghums are much smaller and usually weigh only about as much as average caryopses of wheat, oats, and barley; and seeds of some of the sorgos, particularly Sumac, weigh still less. Proso (*Panicum miliaceum* L.), a grain millet, has extremely small seeds for a cereal crop and makes a correspondingly slow early growth. The sorghums and proso in general have a wider ratio between seed size and final stalk weight at maturity than any other of the American cereal crop plants.

Plantings of cereal varieties having different seed sizes were made on July 13 and August 11, 1936. Included in this experiment were two varieties of corn (*Zea mays* L.), Surecropper and Krug; four varieties of sorghum (feterita, Double Dwarf Yellow milo, Dwarf hegari, and Sumac sorgo); and one variety of proso (Yellow Manitoba). The oven-dry weights per kernel, and per stalk 10 days after planting, of each variety are shown in table 1, and the stalk weights at intervals during periods up to 40 days after planting, which include only a part of the grand period of growth, are shown in figure 2. The stalk weights shown are averages from the two plantings.

In general, a close relationship was found between the size of seed and the size of seedling. The corn variety Surecropper had the largest seed and also the most rapid early growth, while Yellow Manitoba proso had the smallest seed and the least early growth. Krug corn made less early growth than the larger-seeded Surecropper variety but exceeded all of the sorghums. Among the sorghum varieties, feterita had the largest seeds and grew most rapidly during early stages, while Sumac sorgo had the smallest seeds and slowest apparent early growth. A distinct spread between sorghum varieties occurred from the sixteenth to the twentieth day after planting and the stalk weights then were in the same order as the seed weights, except that Dwarf hegari and Double Dwarf Yellow milo were reversed. The seeds of the latter variety usually are larger than those of Dwarf hegari but in these samples they were slightly smaller. The early growth of Double Dwarf Yellow milo exceeded that of Dwarf hegari, as shown in figure 1.

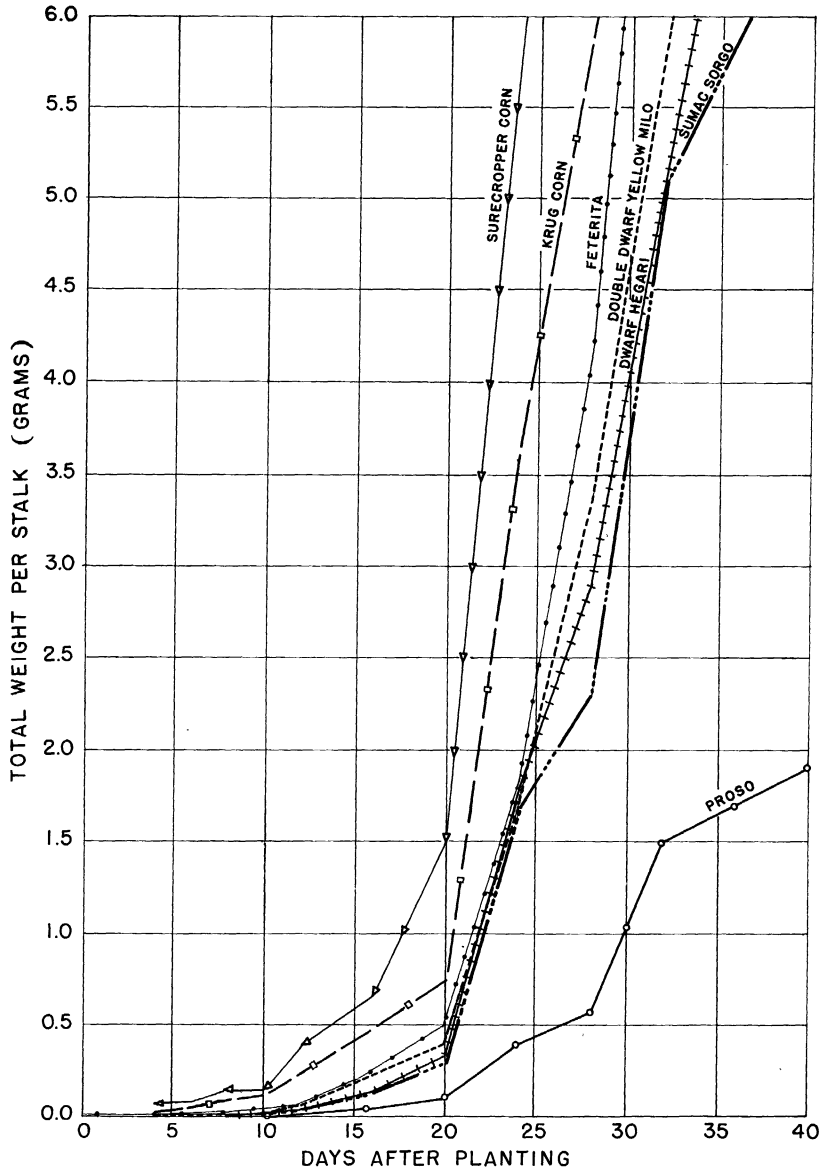

FIGURE 2.—Oven-dry weight per stalk of two varieties of corn, four of sorghum, and one of proso, at Tucson, Ariz., in 1936.

TABLE 1.—*Oven-dry weight per seed, and per stalk 10 days after planting and at different periods thereafter, of 7 cereal varieties*

Crop and variety	Weight per seed	Weight per stalk 10 days after planting	Period after planting for weight per stalk to equal weight per seed
	Mg	*Mg*	*Days*
Corn:			
Surecropper	407.8	149	14
Krug	188.0	112	11
Sorghum:			
Feterita	26.9	38	9
Dwarf hegari	25.9	33	9
Double Dwarf Yellow milo	23.4	37	8
Sumac sorgo	14.2	20	8
Proso:			
Yellow Manitoba	3.1	12	5

An inspection of figure 2 shows that after the seedlings had reached a weight of roughly 0.5g per stalk, the growth-curve rise for the next 5 days was strikingly and almost uniformly abrupt in all varieties. This is in conformity with the monomolecular autocatalytic law, upon which the usual growth curve is based,[5] in which increase in weight varies with the "active mass."

The weight per stalk 10 days after planting, which was previous to a pronounced upturn in the growth curve of any of the cereal varieties, is compared graphically with the weight per seed in figure 3, *A*. A

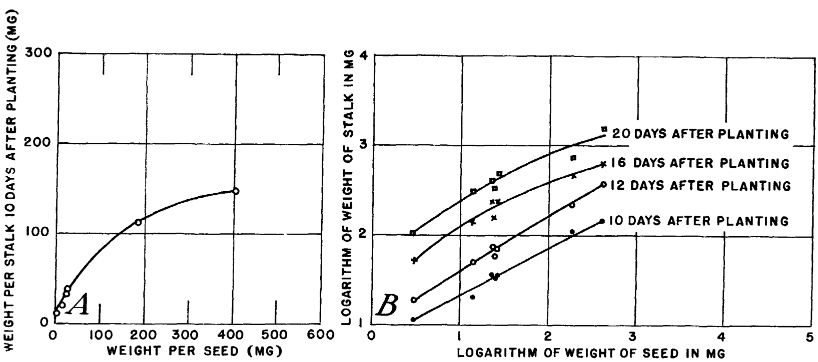

FIGURE 3.—*A*, Relation between weight per seed and weight per stalk 10 days after planting of corn, sorghum, and proso; *B*, relation between logarithms of the seed weights and of the stalk weights taken at various intervals up to 20 days after planting.

curvilinear relationship between stalk weight and seed size is indicated that closely approaches a logarithmic curve. When the logarithms of the two sets of weights are charted (fig. 3, *B*) the points fall approximately on a straight line. The relationship was linear also 12 days after planting. Later, 16 and 20 days after planting, when appreciable growth was occurring, the corresponding points in figure 3, *B*, form slight curves instead of straight lines, which indicates that factors other than seed size were operative in partly determining the weight per stalk at these stages. Ten and twelve days after

[5] ROBERTSON, T. BRAILSFORD. See footnote 3.

planting the logarithm of the weight of the seedling stalks thus varied directly with the logarithm of the weight of the seed of the corn, sorghum, and proso varieties included in the experiment. This is in conformity with the calculation of growth curves, which is based upon a logarithmic relationship between the weight of the plant (or "active mass") and the increase in growth. The results strongly suggest that the size of 10-day-old seedlings of the cereals investigated was determined by the mass of the seed and the apparent slow early growth of the sorghums and proso was merely a logarithmic function of seed size. A growth curve for barley obtained by Pope [6] showed a trend in early growth very similar to that of the sorghums shown in figure 1. Caryopses of barley have approximately the same average weight as those of the grain sorghums Dwarf hegari and Double Dwarf Yellow milo.

Ashby [7] has suggested that vigor in corn hybrids may be due in part to larger embryos, although this view has been challenged by Sprague [8] and others. Incidentally, Sprague's growth data, with one exception, show that the logarithms of seed and seedling weights are proportional.

SUMMARY

Sorghum seedlings are smaller and appear to be slower in early growth than those of corn. The increases in dry weight per stalk and grain weight per head of two grain sorghum varieties, Dwarf hegari and Double Dwarf Yellow milo, grown in the field under irrigation at Tucson, Ariz., from 1931 to 1934, are presented. A planting at a normal date, about June 18, and a later planting, about July 22, were made in each of the 4 years.

About 10 to 15 percent of the final dry weight of the stalks and heads was produced during the first half of the growing period. The growth curves of the two varieties in both plantings indicated a much slower increase in growth in early stages of development and a more rapid increase at later stages than would be expected from the usual symmetrical sigmoid growth curve typical of many plants.

Two varieties of corn, four of sorghum, and one of proso, representing a wide range of seed sizes, were planted in the field in 1936, and the rate of early growth was determined. A close relationship was found between the size of seed planted and the dry weight per stalk in the early stages of plant development. In young seedlings of corn, sorghum, and proso, 10 and 12 days after planting, the logarithm of the weight per stalk was directly proportional to the logarithm of weight per seed. Seedling size thus was a logarithmic function of the "active mass" in the seed. The wider ratio between the weight of the seed and the weight of the mature stalk appears to explain for the most part the smaller seedlings and apparent slower early growth of sorghum and proso, as compared with corn, under optimum growing conditions.

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[6] POPE, MERRITT N. THE GROWTH CURVE IN BARLEY. Jour. Agr. Research 44: 323-341, illus. 1932.

[7] ASHBY, ERIC. STUDIES IN THE INHERITANCE OF PHYSIOLOGICAL CHARACTERS. 1. A PHYSIOLOGICAL INVESTIGATION OF THE NATURE OF HYBRID VIGOUR IN MAIZE. Ann. Bot. [London] 44: [457]-467, illus. 1930.

[8] SPRAGUE, G. F. HYBRID VIGOR AND GROWTH RATES IN A MAIZE CROSS AND ITS RECIPROCAL. Jour. Agr. Research. 53: 819-830, illus. 1936.