GROWTH, NUTRIENT UPTAKE AND GRAIN YIELDS OF INTERCROPPED SORGHUM [*SORGHUM BICOLOR* (L.) MOENCH] AND PEARL MILLET [*PENNISETUM AMERICANUM* (L.) LEEKE]

by

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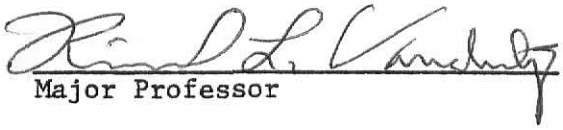

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INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] and pearl millet [*Pennisetum americanum* (L.) Leeke] are among the most important food crops in the semiarid regions of the world, especially in Africa and India. In these areas, multiple cropping of both crops is common practice. Since the cost of labor is low, most field work is carried out by hand, which allows random mixtures and large differences in maturity of both crops. According to Ruthenberg (1971), mixed cropping not only has ecological advantages such as a reduction in susceptibility to pests and diseases, better soil cover, adaptation of planting to changing soil conditions, better utilization of growth resources, especially light, but also delivers a continuous food supply to the small farmer. In addition, Norman (1972) found in Nigeria more efficient labor use and less variable returns from year to year in intercrops than in monocultures.

Where the cost of labor is high and mechanization is required, multiple cropping appeared not to be feasible. Therefore, agricultural science did not pay much attention to multiple cropping for a long time and considered it a primitive system.

Adapting multiple cropping of sorghum and millet to high levels of mechanization, some advantages of mixed cropping as traditionally used, for instance in Nigeria, disappear. The crops have to be planted in rows, and only small differences in maturity can be used since they have

to be planted and harvested at the same times. Weed control becomes more difficult since millet is more susceptible to herbicides than sorghum. Difficulties in harvesting may occur due to different grain sizes or differences in maturity. However, some advantages may still remain, yield increases seem likely, susceptibility to diseases and pests may be less.

The purpose of this study was to see,

- if relatively small temporal differences (in combination with spatial differences) would result in yield increases
- how large the yield increases due to spatial differences would be
- if small temporal differences would result in different dates of maximum nutrient uptake and thus less competition at these times
- if differences between the two species in nutrient uptake occur
- if the intercropping treatments would show better light use and produce more dry matter
- which planting patterns would use the 'positive' intercropping effects best
- how good moisture supply (irrigation) would influence the points above
- how climatic differences (different locations) would influence yields.

LITERATURE REVIEW

Definitions

Because some technical terms describing polyculture systems are occasionally confusing, some definitions might be helpful to avoid misunderstandings.

Multiple cropping: Describes forms of cropping practices, where total production from a unit area of land in a farming year is achieved through growing crops simultaneously, sole crops in sequence, or a combination of mixed and sole crops in sequence (Andrews and Kassam, 1976).

Mixed cropping: Two or more crops grown simultaneously and intermingled; no row cultivation (Ruthenberg, 1971).

Intercropping: Two or more crops grown simultaneously in alternate rows in the same ground (Ruthenberg, 1971).

Row intercropping: Growing two or more crops simultaneously where one or more crops are planted in rows (Andrews and Kassam, 1976).

Yield Comparison in Intercropping Systems

In comparing intercropping yields, the question of which unit to compare arises. Adding the yields of intercrops in weight units (kg/ha)

and comparing them to a particular component crop in monoculture involves the problem of comparing different things with different nutritional or monetary values. Comparing yields per unit area in monetary terms is only for one particular situation in one particular area at one particular time of value. All kinds of comparison methods can be found in the literature (Kass, 1978; Willey, 1979). Recently the most common basis for comparison is the land equivalent ratio (LER) concept. It is defined by Trenbath (1976) as:

$$LER = \sum \frac{y_i}{y_{ii}}$$

where y_i is the yield of the i^{th} component in the intercrop on one unit area and y_{ii} is the yield of the same crop in the same area in a sole stand. The sum of all fractions $\frac{y_i}{y_{ii}}$ gives the LER. If the LER equals 1, the intercrop yield is the same as if both components had been grown separately in the same area. An LER > 1 indicates intercrop yield advantages, whereas an LER < 1 means that intercrop yields are lower than sole crop yields that would have been obtained from the same area by monoculture.

Competition Concepts

Competition occurs between plants of the same species (intraspecific competition) and plants of different species (interspecific competition). Intraspecific competition is usually high because all plants compete for the same growth factors at the same time. Willey (1979) differentiates between three cases in interspecific competition:

(1) mutual inhibition which he considers rarely occurs, where the productivity of all components is less than expected in sole stands; (2) mutual cooperation, where the productivity of all components is higher than in sole stands; and (3) compensation, where one or more components produce less than in sole stands, but higher productivity of other components compensates for this suppression.

Different approaches in determination of competition effects have been made. Especially in the older literature, competition was defined as a function of plant density. Additive models used a standard population density and added different species at various densities. This method was mainly used in weed ecology, where the influence of weeds at different densities on crops was investigated. Substitutive models, which are used in multiple cropping research (deWit, 1961; Baeumer and deWit, 1968; Donald, 1963) use replacement series in which one crop is replaced at different quantities by one or more different crops.

Although these models are capable of quantifying the magnitude of competition in time, they do not explain and quantify what the plants compete for at certain times.

Theoretically plants compete for soil factors (nutrients, water, oxygen) and light. Kanemasu et al. (1979) found usually high turbulences in crop canopies, and Trenbath (1976) concluded that competition for carbon dioxide is unlikely to occur in nature.

Competition and Intercrop Yields

Generally speaking, intercrop yields will be higher compared to sole crop yields if interspecific competition is lower than intraspecific

competition, or in other words if the different intercropping partners use the resources in different ways rather than competing for them. Willey and Rao (1977) differentiate between temporal and spatial effects in regard to utilization of the growth factors. According to them, "better temporal use of growth resources may occur when the component crops have different growth patterns and thus make their major demands on the environment at different times." Better spatial use is likely, when the intercropped species differ in their morphology which may lead to occupation of different soil layers by their root system or better light utilization by different canopy structures.

The sorghum/millet intercropping literature shows experiments with high temporal differences between crops. Andrews (1972) intercropped a very early maturing millet variety with a much longer maturing sorghum and found yield increases, dependent on the spatial arrangement, of up to 50%. Kassam and Stockinger (1973) planted sorghum and millet on May 15, harvested millet as soon as August 18, whereas sorghum was harvested on November 14. Yield increases of 19% were observed compared to sole sorghum yields. Baker and Norman (1975), working in Nigeria, developed a quadratic equation which indicated that intercrop yields were higher than sole crop yields if the time difference between crops was at least five weeks. In sixteen combinations with four millet and four sorghum lines in India, Willey and Rao (1977) found the highest yield increase of 32% on an LER basis in a combination with the largest temporal difference between crops although there was no correlation between temporal difference and yield over the experiment as a whole.

Temporal and Spatial Effects of Resource Utilization

Light

Willey and Roberts (1976), cited by Willey (1979) considered light the most important factor in achieving better temporal utilization of the growth factors. As light is 'instantaneously available' and has to be 'instantaneously intercepted' (Donald, 1961), best use of light can therefore be made if the crop canopy covers the soil as completely as possible for the longest possible time of the growing period. This was demonstrated with a sorghum/pigeon pea mixture of ICRISAT. To achieve that effect in a sorghum/millet intercrop it would mean the use of, for instance, a fast growing, early maturing millet which builds up a full canopy quickly, and a slower growing, later maturing sorghum, which uses the available radiation at the end of the growing season. This combination was investigated by Andrews (1972) and Kassam and Stockinger (1973). The latter demonstrate higher dry matter production in the intercrop than in either of the sole crops which indicates higher net photosynthesis through better light utilization over the growth period.

Trenbath (1976) states that under conditions where soil factors are not limiting, and the plant is vegetative, growth rates are proportional to the light intercepted, and under these conditions even small height differences can lead to strong competition. This agrees with results of Andrews (1974) who intercropped pearl millet with four sorghum lines of different heights, ranging from 1.22m to 3.73m. He obtained the highest millet yields (2016 kg/ha) from the combination with the shortest sorghum line and the lowest yield (1572 kg/ha) from

the combination involving the tallest sorghum line, although the time of competition in those combinations--early maturing millet, late maturing sorghum--was comparatively short.

Francis et al. (1976) compared normal and dwarf maize hybrids in sole stands and when intercropped with bush beans. Although maize yields did not differ significantly, neither between hybrids nor between systems, bean yields were more reduced in systems with the taller maize hybrid (63%) than with the dwarf hybrid (52%), compared to monoculture.

Although there is no doubt that intercropping systems can use light better in a temporal sense if the crops have different growth cycles, there seems little evidence for better spatial use. Willey (1979), citing Willey and Roberts (1976) stresses that sole crops at optimum population densities are usually capable of achieving maximum light interception.

Trenbath (1976) lists changes of plants due to shading. He differentiates between adaptive and nonadaptive changes. Adaptations to low light intensity are lowered root/shoot ratios, lower dark respiration, and decreased leaf area, weight, and stem elongation of the shaded plant. Nonadaptive changes are earlier leaf senescence and reduction of maximum photosynthetic rates.

Temporal Considerations of Nutrient Uptake and Dry Matter Accumulation

Nutrient uptake of crop combinations, especially the temporal aspects of times of maximum nutrient uptake has to be considered since interspecific competition can be lowered, if maximum demands

of the different crops for nutrients differ in time (Willey and Rao, 1977).

Detailed work has been done for sorghum in regard to nutrient uptake and dry matter accumulation in time (Vanderlip, 1972; Roy and Wright, 1973, 1974; Herron et al., 1963). Roy and Wright (1973) found maximum dry matter accumulation rates during peak vegetative growth shortly before flowering (35 to 42 days after emergence with sorghum hybrid CSH-1). Although N and P accumulation were increasing almost linearly until maturity, there were peaks at maximum vegetative growth and during grain filling (70-91 days). Herron et al. (1963) found with sorghum hybrid RS 610 peaks in dry matter accumulation and N uptake coincided at the late boot and soft dough stage.

Kassam and Stockinger (1973) showed for sole sorghum dry matter accumulation peaks between floral initiation and flowering and shortly after flowering.

While dry matter accumulation, nitrogen and phosphorus uptake correspond very well (Roy and Wright, 1973, 1974), potassium uptake rates were faster early in the growth cycle and decreased. Depending on the level of fertilization, 70-90% of the total K uptake had already taken place before heading.

Blondel (1971), cited by Kowal and Kassam (1978) investigated nitrogen uptake in pearl millet and found a rapid increase in uptake rates after panicle initiation, with peaks at heading and zero uptake rates after flowering. Kassam and Stockinger (1973) also found dry matter accumulation and N uptake rates increasing at or shortly before panicle initiation, but nearly linear rates thereafter.

Although environmental and genetic differences play an important role, sorghum and millet seem to have their maximum nutrient demands, especially for nitrogen, at the same stages of development. This indicates that competition for nutrients at times of maximum demands can probably be lowered using crops with different growth periods in multiple cropping. Nitrogen uptake and dry matter accumulation for a sorghum/millet intercrop were investigated by Kassam and Stockinger (1973), using an early maturing millet and a much later maturing sorghum variety. In that combination, millet was harvested before flowering of sorghum. Millet took up nitrogen and accumulated dry matter at high rates almost linearly from shortly before panicle initiation on and used the nitrogen resources at 140 kg/ha, leaving only 40 kg/ha for uptake by sorghum. Nitrogen use by the intercrop was higher than by either of the monocultures.

Spatial Arrangement

Space itself is not a resource, but since the growth factors are distributed in space, spatial arrangement is of importance. Andrews (1972) compared in a sorghum/millet intercrop three different planting patterns: 1:1 row, 1 row of sorghum : 2 rows of millet, and a 2:2 row arrangement. He obtained the highest intercrop yields in the 1:1 and 1:2 row arrangements, but, at least for millet, significantly lower yields in the 2:2 row pattern. Francis et al. (1976) found in a maize/beans intercrop lower bean yields in alternate rows as compared to within-row mixtures, but no effect on maize.

Although contradictory experimental results exist for different crop combinations (Kass, 1978), there is some evidence that, at least for sorghum/millet combinations, space is used better the more 'border effects' occur between the intercropping partners.

Optimum Population Densities

The question of optimum population densities in a sorghum/millet intercrop is not sufficiently answered. Andrews (1972) suggests that optimum population densities for the intercrop may be higher than for sole crops. Osiru and Willey (1972) found optimum population densities for a sorghum/bean mixture higher than for sorghum, but the same as in sole stands for beans. Willey and Rao (1977) reported a maize/pigeon pea experiment at ICRISAT where the total intercropping advantage was 35% at sole crop optimum, but 45% at populations 50% higher. Generally, with higher populations competition increases (Kass, 1978) and more competitive crops have more benefit, while the other crop(s) will be more suppressed. Nevertheless, Andrews and Kassam (1976) state that high yielding cultivars "give optimum yields over a wide range of population densities." Especially in sorghum/millet mixtures population densities do not seem to be very critical, since at least millet is variable in occupation of space by tillering.

Fitting the Intercropping Partners

Obviously, not all combinations between sorghum and millet cultivars give the same benefit in terms of an LER increase. In an experiment conducted at ICRISAT (Willey and Rao, 1977) where four millets were

combined with four sorghums, three of the four combinations involving the millet GAM 73 only gave yields on an LER basis of 0.98, 0.99 and 1.04, and ranked 13th to 15th of the 16 combinations. However, which specific plant characteristics are important for multiple cropping ability is unknown, since no significant correlations were found either between height differences and yield or between maturity differences and yield.

MATERIALS AND METHODS

Three sorghum hybrids, ACCO 1014, Pioneer 8324 and DeKalb F67, were planted in sole stands and intercropped as within-row mixtures and in alternate rows with pearl millet hybrid 2159 x 7024 developed by W. D. Stegmeier, Ft. Hays Experiment Station, Hays, Kansas.

ACCO 1014, Pioneer 8324 and DeKalb F67 were selected to represent early, medium and late sorghum hybrids, respectively. They were good yielding hybrids not too different in plant height from millet. The millet hybrid was suggested by the breeder as medium in maturity and good yielding.

The study contained the following ten treatments:

	Sorghum	Millet	Cropping system
1.	ACCO 1014	---	sole stand
2.	Pioneer 8324	---	sole stand
3.	DeKalb F67	---	sole stand
4.	ACCO 1014	2159 x 7024	alternate rows
5.	Pioneer 8324	2159 x 7024	alternate rows
6.	DeKalb F67	2159 x 7024	alternate rows
7.	ACCO 1014	2159 x 7024	within-row mixture
8.	Pioneer 8324	2159 x 7024	within-row mixture
9.	DeKalb F67	2159 x 7024	within-row mixture
10.	---	2159 x 7024	sole stand

Each treatment was replicated four times. The experiment was planted on 28 May 1980 on the Ashland Experiment Field near Manhattan, Kansas, on a silt loam; on 29 May 1980 at the Sandyland Experiment Field, St. John, Kansas, on a Pratt loamy fine sand; and on 3 June 1980 at Garden City Branch Experiment Station on a Keith silt loam. For all plantings, a double row cone planter was used, adjusted to a row width of 76 cm. In Ashland, a dryland and an irrigated study was planted. Each plot consisted of eight rows, 13m long, of which the four center rows were used for sampling and for harvest at maturity. Plots at St. John and Garden City were six rows wide and eight meters long. The two center rows were used for harvest at maturity. Plant populations were 130,000 plants/ha in Ashland and 75,000 plants/ha in St. John and Garden City. The ratio between sorghum and millet in intercrops was 1:1. Weeds were controlled in Ashland by pre-emergence application of 2.2 kg/ha of propazine. The remaining weeds, mainly ground cherry (Physalis heterophylla), climbing milk weed (Ampelamus albida), large crab grass (Digitaria sanguinalis) and fall panicum (Panicum dichotomiflorum) were controlled mechanically. In Garden City, weeds in the early stages of the crop were controlled mechanically; 2,4 D was applied to control puncture vine (Tribulus terrestris) ca. eight weeks after the crop had emerged. No herbicides were available for the light soils at St. John, so all weed control was carried out mechanically.

Fertilizer was applied before seedbed preparation according to recommendations based on soil analysis for sorghum. Furrow irrigation was applied with gated pipes weekly from the second week of July on to

the irrigated study at Ashland. To determine dry matter accumulation and nutrient uptake, plant samples were harvested in Ashland on 7, 12, 18, and 25 July and 1 and 8 August and at physiological maturity of the crops. One meter of two of the four center rows of each plot was cut, chopped into small pieces and dried at 70 C. On the last two sampling dates, the plants were separated into heads and stalks with leaves (vegetative parts).

After determination of dryweight of each crop, subsamples were ground and analyzed for N, P and K. The dried subsamples were digested with concentrated sulfuric acid, using hydrogen peroxide as a catalyst. Nitrogen and phosphorus were determined colorimetrically with a Technicon Autoanalyzer (Linder and Harley, 1942; Technicon Ind. Sys., 1977). Potassium was determined by flame emission. From these data, dry matter, nitrogen, phosphorus, and potassium accumulation for each component crop in kg/half hectare and for the 'whole' treatment in kg/ha were calculated. For the last two sampling dates, all variables were calculated separately for heads and vegetative parts.

Leaf canopy heights were determined for both species separately, as far as possible, on 2 July. Mature heads were hand harvested, separated by species from 3.0 m of each of the four central rows at Ashland and 4.5 m of each of the two center rows at Garden City and St. John. Harvested heads were threshed with an Ames experimental plot thresher. Basic plot data were, separately for each component crop, converted into kg/.5 ha or kg/ha, respectively, and adjusted to 12.5% moisture. Thousand seed weight was determined, heads per half hectare, seeds per head, headweight, and LER's were calculated for

each species. Total LER and total treatment yields per hectare also were calculated.

All computations and statistical analyses were carried out with the statistical package SAS. Analysis of variance was computed with SAS's PROC ANOVA and PROC GLM. Comparisons for sorghum and millet were made between cropping systems and sorghum hybrids. For 'total' treatments, sole stands of sorghum were compared to alternate rows and within-row mixtures. Orthogonal comparisons were made between millet in sole stands and intercrops (not differentiated between within-row mixtures and alternate rows). Comparisons were also made between studies in Ashland to get an idea of the effect of limited moisture on the relationship between species as influenced by cropping system and differences in growth cycle.

RESULTS AND DISCUSSION

Dry Matter, Nitrogen, Phosphorus and Potassium Accumulation During the Growing Season

Ashland Irrigated

Dry matter, N, P, and K accumulation of sorghum and millet as affected by cropping systems are shown in Figure 1 and Tables A2-A9. Dry matter accumulated by sorghum was significantly different among cropping systems only on Julian day 213. Sole stands were significantly higher than within-row mixtures, alternate rows not being significantly different from either sole stands or within-row mixtures. Dry matter accumulation by millet (Fig. 1b) was significantly highest in within-row mixtures and lowest in sole stands on Julian day 193. By late grain filling, however, millet in alternate rows produced significantly more dry matter than in within-row mixtures.

Nitrogen uptake by sorghum was significantly highest in alternate rows on Julian day 188. From Julian day 193 on, about four days before millet flowering, competition from millet increased resulting in sole stands of sorghum taking up more nitrogen than sorghum in mixtures (significantly so on Julian days 199, 206 and 213). During the later part of grain filling, especially sorghums in within-row mixtures were able to take up significant amounts of nitrogen, resulting in statistically significant differences between them and sole stands, but

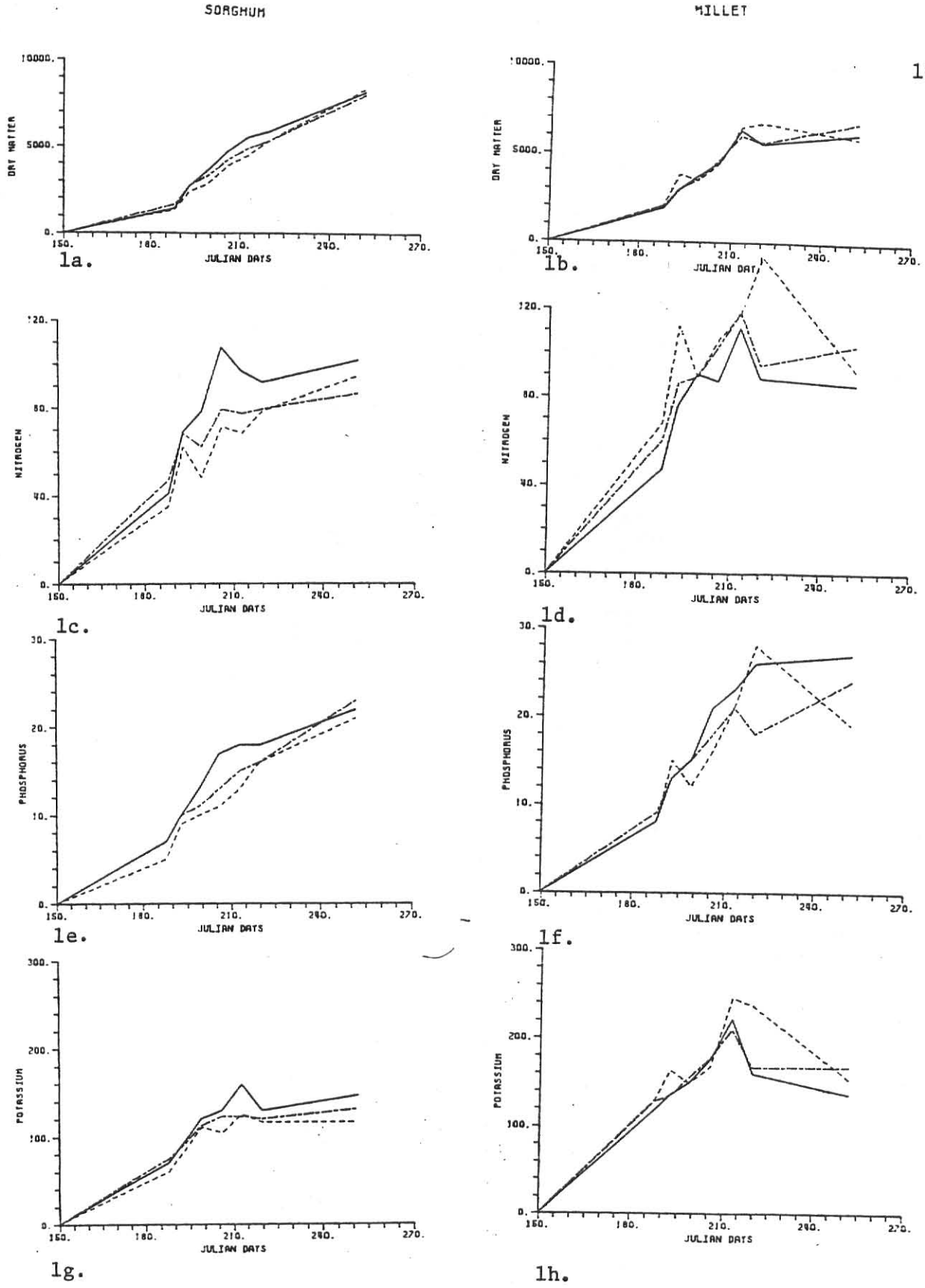

Figure 1. Dry matter and nutrient accumulation by sorghum and millet, averaged by cropping system, Ashland irrigated.

nitrogen accumulation by sorghum in sole stands was still higher than in alternate rows.

Millet nitrogen uptake was significantly different among cropping systems on Julian day 193, four days before flowering. High demands of millet could be supplied significantly better in within-row mixtures than in sole stands or alternate rows. In within-row mixtures, more direct interspecific interactions took place, and millet was competing more successfully for nitrogen than sorghum. From flowering on, no significances could be found until the end of grain filling, when millet in alternate rows had accumulated significantly more nitrogen than in sole stands or within-row mixtures.

Phosphorus uptake by sorghum (Fig. 1e) was significantly higher in sole stands and alternate rows than in within-row mixtures on Julian day 188. On Julian days 206 and 213, sole stands had taken up significantly higher amounts of P than sorghum in either mixture. During grain filling, sorghum in mixtures compensated (due to reduced millet competition) so no significant differences existed at physiological maturity.

Millet P accumulation (Fig. 1f) was significantly higher in sole stands and alternate rows compared to within-row mixtures at maturity.

Sorghum potassium uptake (Fig. 1g) was not dependent on cropping systems until Julian day 213. From then on, sole stands of sorghum had significantly higher K uptake than sorghum in within-row mixtures, alternate rows being in between.

Potassium uptake by millet (Fig. 1h) did not show any significant differences among cropping systems during growth of millet. Potassium losses, presumably by leaching, occurred after millet physiological

maturity, since the mature millet was left in the field until sorghum harvest. Thus, significant differences in K accumulation of millet at the end of the season were mainly a result of unequal losses. Millet protected by sorghum did not have losses as high as sole stands of millet.

Sole crop sorghum showed a general superiority over sorghum in mixtures. This was the case especially during the period of maximum nutrient demands around flowering and at the beginning of grain filling. Later in the growing season, when millet was already mature, sorghum in mixtures could compensate for competition by millet (steeper slope of mixed sorghum curves during the end of the growing season).

Millet in sole stands was superior to millet in mixtures only with respect to P uptake. Dry matter, N and K accumulation tended to be higher in mixtures than in sole stands. A distinct peak was observed on Julian day 193 for dry matter and N accumulation by millet in within-row mixtures.

Figure 2 shows the effects of sorghum hybrids or sorghum hybrids intercropped with, averaged over cropping systems on dry matter, N, P, and K accumulation.

Sorghum hybrids did not differ significantly in dry matter accumulation (Fig. 2a) until Julian day 206. From then on, ACCO growth declined while Pioneer and DeKalb still had high growth rates, resulting in significantly higher dry matter values for Pioneer and DeKalb than for ACCO on Julian day 213 and at physiological maturity. Sorghum hybrids did not have any significant influence on millet dry matter production (Fig. 2b) until late in grain filling when millet intercropped with ACCO produced significantly more dry matter than with

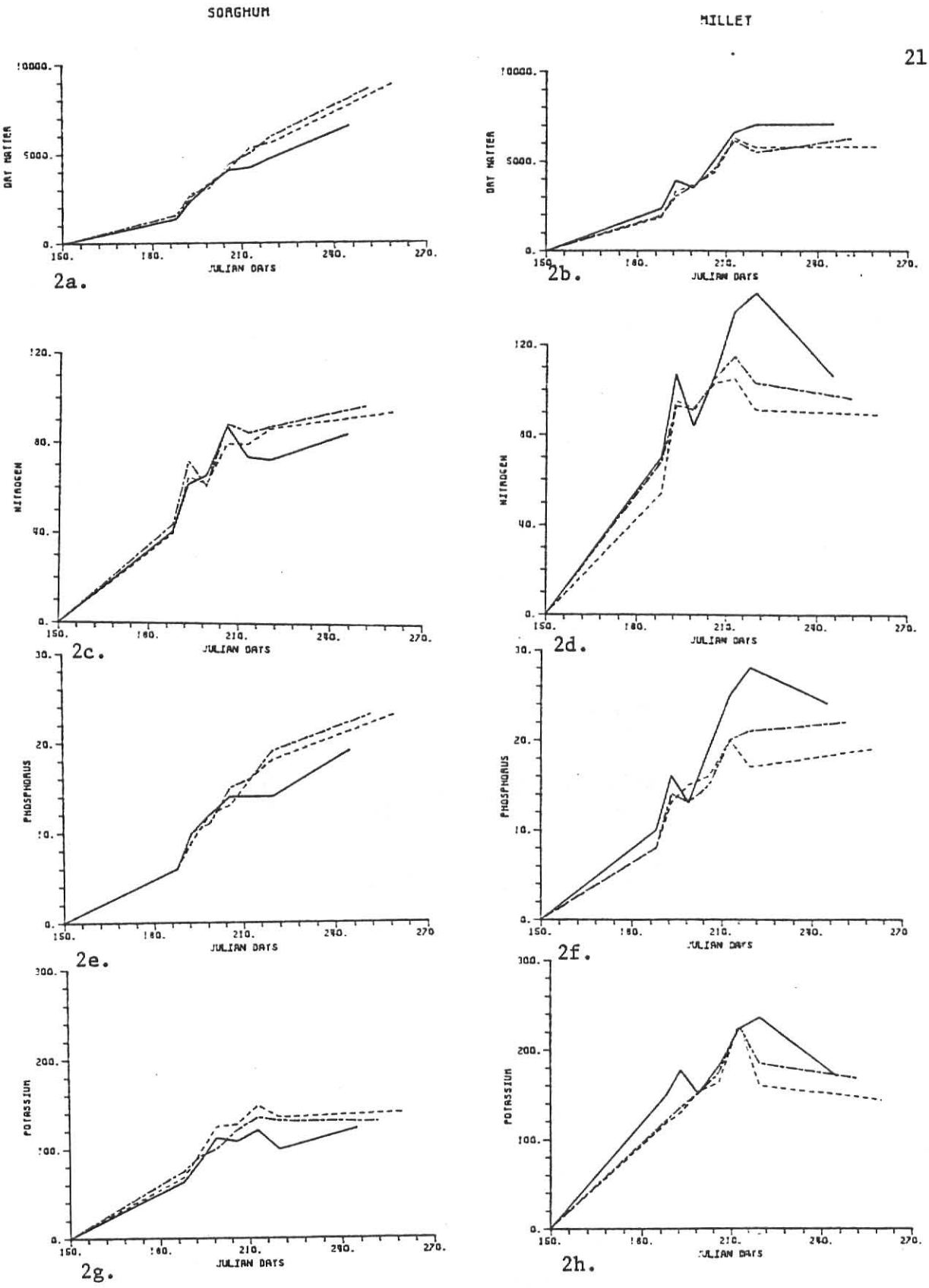

Figure 2. Dry matter and nutrient accumulation by sorghum and millet, averaged by sorghum hybrid, Ashland irrigated.

DeKalb. Treatments with Pioneer were not significantly different from either.

Nitrogen accumulation by sorghum (Fig. 2c) was not significantly dependent on hybrids throughout the growing season. Millet N accumulation (Fig. 2d) was significantly higher when intercropped with ACCO than intercropped with DeKalb on Julian day 213 and physiological maturity. Millet intercropped with Pioneer did not differ significantly from either one.

Phosphorus uptake by sorghum (Fig. 2e) did not differ significantly among hybrids until Julian day 220. From then on, ACCO accumulated less P than Pioneer and DeKalb. Phosphorus uptake by millet was, like N uptake, significantly higher when intercropped with ACCO than when intercropped with Pioneer and DeKalb from Julian day 213 on.

Potassium uptake by sorghum (Fig. 2g) was different among hybrids on Julian days 213 and 220. No significant amounts of potassium were taken up thereafter. Potassium uptake by millet was significantly higher when intercropped with ACCO than when intercropped with either of the other hybrids on Julian day 193. No significant differences could be observed thereafter. Due to the longer period millet was standing in the field after maturity, millet intercropped with DeKalb had significantly higher losses of K than when intercropped with Pioneer or ACCO.

Except for K accumulation by millet on Julian day 193, no significant hybrid effects could be observed prior to grain filling. Significant differences developed during the second half of grain filling in millet with respect to dry matter, N, and P accumulation, and during

the same time in sorghum with respect to dry matter, P and K. Potassium and nitrogen uptake preceded dry matter production.

Significant sorghum x cropping system interactions are shown in Figure 3. It was obvious with ACCO that sole stands produced higher amounts of dry matter throughout the growing season. Pioneer and DeKalb, however, had higher growth rates in mixtures after Julian day 220, resulting in higher dry matter yields of the intercropped sorghum as compared to sole stands with DeKalb, and in higher dry matter yields of sorghum in alternate rows as compared to sole stands with Pioneer.

Curves of the corresponding millets illustrate the complementarity of both crops. Millet was almost mature and not competing with sorghum after about Julian day 230, so sorghum in mixtures could use the advantage of reduced competition and compensate or even overcompensate for millet competition before. This emphasizes the importance of freedom from competition during grain filling and explains yield increases of traditional intercropping systems using wide temporal differences compared to sole crops.

Total dry matter, nitrogen, phosphorus and potassium accumulation. The question of whether mixtures of sorghum and millet can use environmental resources better than respective sole stands was investigated by comparison of total dry matter production (as a parameter for the efficiency of photosynthesis) and nutrient uptake.

Table 1 shows total dry matter, N, P, and K accumulation. Sole millet values marked with an asterisk are significantly different from sorghum/millet mixtures.

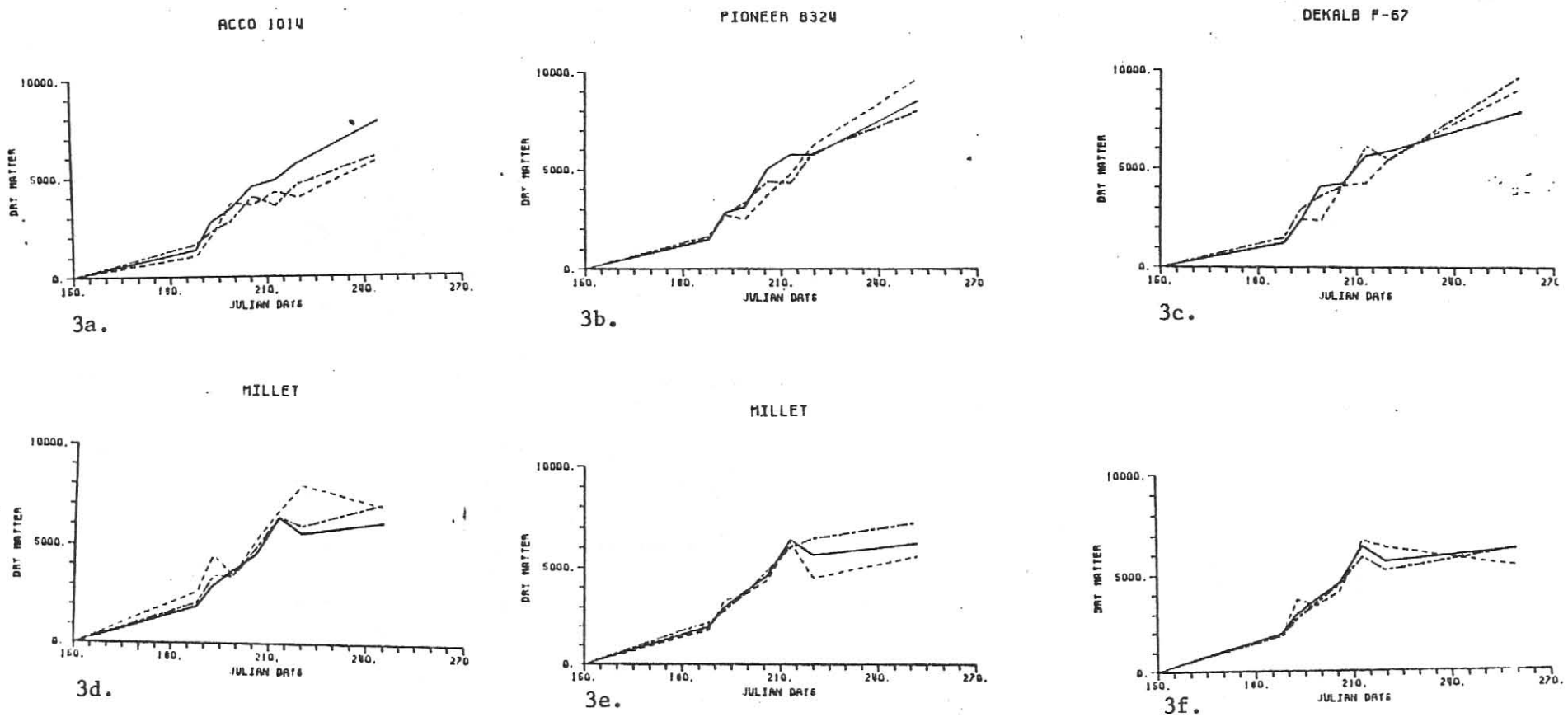

Figure 3. Dry matter of three sorghum hybrids and corresponding millet.

Table 1. Total dry matter, nitrogen, phosphorus and potassium accumulation (kg/ha), Ashland irrigated. Cropping systems averages.

	dry matter	N	P	K	Julian day
sole millet	3874.7	93.36	16.06	235.5*	188
sole sorghum	2724.2 b	82.16 b	13.06 b	140.1 b	
alternate rows	3641.7 a	107.09 a	15.33 a	202.6 a	
within-row mixt.	3317.6 a	102.00 ab	12.89 b	184.3 a	
sole millet	5948.2	151.26	25.90	269.5*	193
sole sorghum	5329.3 b	137.80 c	20.14 b	186.1 b	
alternate rows	5753.4 ab	154.80 b	23.52 a	226.0 a	
within-row mixt.	6222.7 a	175.70 a	23.52 a	240.3 a	
sole millet	7578.7	179.15	29.06	298.3	199
sole sorghum	7072.3	155.13	25.76	242.7	
alternate rows	6937.9	151.76	26.32	268.7	
within-row mixt.	6040.4	133.56	21.80	238.1	
sole millet	9090.1	173.67	41.15*	349.3*	206
sole sorghum	9278.2	213.28	34.90 a	258.7	
alternate rows	8908.1	183.30	31.62 ab	300.1	
within-row mixt.	8333.3	177.14	27.22 b	271.7	
sole millet	12805.1*	222.08*	46.67*	441.1*	213
sole sorghum	10909.4	191.09	36.54	318.7 b	
alternate rows	10927.6	195.58	37.23	329.5 b	
within-row mixt.	10985.3	185.45	34.40	370.5 a	
sole millet	11312.3	177.01	51.92	317.7	220
sole sorghum	11574.8	182.00	34.74	257.3	
alternate rows	10987.1	183.41	37.83	315.3	
within-row mixt.	11491.4	200.19	40.46	330.7	
sole millet	12440.9*	170.09	54.53	273.0	ph.mat.
sole sorghum	16233.6 a	202.00	43.59 ab	291.8 a	
alternate rows	14866.4 b	190.20	46.73 a	300.3 a	
within-row mixt.	14192.3 b	184.10	39.08 b	267.3 b	

Total dry matter production during the early stages was dependent on cropping systems with significantly higher values for both mixtures than for sole stands of sorghum on Julian day 188 and significantly higher values for within-row mixtures than for sole stands of sorghum on Julian day 193. After flowering of millet, these significances disappeared. Sole stands of millet were significantly higher than mixtures on Julian day 213 and significantly lower than these at physiological maturity of the sorghums. Sorghum hybrids influenced total yields only at physiological maturity resulting in significantly higher values for treatments with DeKalb and Pioneer than for ACCO.

Total nitrogen accumulation also was significant among cropping systems only before millet flowering. Alternate rows had significantly higher N accumulation than sole stands of sorghum on Julian day 188, and both mixtures had significantly higher N uptake than sole sorghum on Julian day 193. Sole stands of millet were significantly higher in N uptake than mixtures on Julian day 213. Sorghum hybrids did not influence N uptake significantly.

Total phosphorus uptake in alternate rows was significantly higher than in sole stands of sorghum and within-row mixtures on Julian day 188. On Julian day 193, both mixtures had higher P uptake than sorghum in sole stands. On Julian day 213 and at physiological maturity, least P uptake had taken place in within-row mixtures. On Julian days 206 and 213, sole millet had taken up significantly more P than the mixtures.

Total potassium taken up on Julian day 188 and 193 was significantly higher in mixtures than in sole stands of sorghum. On Julian day 213, sole stands and alternate rows had taken up significantly lower amounts

of K than within-row mixtures. At physiological maturity, alternate rows and sole sorghum had taken up significantly higher amounts of K than within-row mixtures. Sole stands of millet had taken up significantly higher amounts of K on Julian days 188, 193, 206 and 213 than mixtures.

Total potassium uptake was greatly influenced by millet, which had consistently higher K contents than sorghum. Thus, when millet was mature and sorghum still growing, in mixtures with the two later sorghum hybrids, the ratio of millet to total biomass declined and also the total potassium uptake in comparison to sole stands of sorghum.

The question of whether intercrops can better use the growth factors available cannot be answered generally. Mixtures tended to be superior over sole sorghum with respect to dry matter production prior to flowering. After maximum leaf area had developed, these differences disappeared, and sole stands of sorghum outyielded sorghum/millet mixtures. It must be assumed that under optimum population densities, no big differences between sole stands and mixtures exist and that dry matter production rates are not dependent on cropping systems once the optimum LAI is reached.

Grain filling. To get an idea of translocation of photosynthates and minerals from vegetative parts into heads, the sampled sorghum and millet plants were separated into heads and remaining (vegetative) parts on Julian day 220 and physiological maturity. Results are shown in Tables A10-A11.

Table A36 shows the analyses of variance over both days for sorghum. Only the temporal effects shall be considered here. No significant differences for dry matter and K in vegetative sorghum parts existed between Julian day 220 and physiological maturity, indicating that no significant amounts of 'dry matter' (predominantly carbohydrates) and K were mobilized in the vegetative tissue and translocated. The fact that dry matter, N, and P showed significant differences in the heads (Table 2) between days indicates that only, or predominantly, those compounds that were taken up or synthetized during the period between Julian day 220 and physiological maturity were translocated into the head. This emphasizes the importance of uptake and synthesis during grain filling with respect to grain yield. No significant day x cropping system interactions occurred for heads or for vegetative parts. Day x sorghum interactions were highly significant for vegetative sorghum parts with respect to N and P (Table 3) and for sorghum heads with respect to dry matter, N, P, and K. This indicates differences in hybrids in mobilization and translocation of N and P out of the vegetative parts, which is not surprising, considering that on Julian day 220 the early sorghum was nearer maturity than the late hybrid.

Table A37 shows the analyses of variance over both days for millet. Here, too, only the temporal effects are of interest. However, no significant differences were found, first, because of the high number of missing values due to sample processing problems and second, millet was already about 20 days into grain filling.

Table 2. Dry matter, nitrogen, phosphorus and potassium uptake by sorghum heads (kg/.5 ha) on Julian day 220 and physiological maturity, Ashland irrigated.

	dry matter		nitrogen		phosphorus		potassium	
	220	p.m.	220	p.m.	220	p.m.	220	p.m.
ACCO	2665 a	3658 b	44 a	58	9.3 a	13.3	31 a	23
Pioneer	2826 a	4691 a	46 a	63	9.6 a	14.8	33 a	21
DeKalb	1505 b	4278 a	23 b	57	4.5 b	13.3	17 b	20

Table 3. Nitrogen and phosphorus uptake by vegetative sorghum parts (kg/.5 ha) on Julian day 220 and physiological maturity, Ashland irrigated.

	nitrogen		phosphorus	
	220	p.m.	220	p.m.
ACCO	29 c	26 b	5.0 c	5.3 c
Pioneer	41 b	35 a	8.9 b	8.4 b
DeKalb	64 a	38 a	13.2 a	9.8 a

Canopy heights. Table 4 shows the values for sorghum and millet canopy heights under irrigation. The analysis of variance (Table A69) showed no dependence of sorghum height on cropping systems. Pioneer and DeKalb were significantly taller than ACCO, as was to be expected since early sorghum hybrids are usually shorter than late ones. Significant sorghum x cropping system interactions did not occur. This means no height adaptation took place. Considering the relatively little difference between millet and the sorghum hybrids, there obviously was no reason for height adaptation under irrigation. Neither cropping systems nor sorghum hybrids intercropped with had significant influence on millet heights (Table A69).

Table 4. Canopy heights (irrigated) on July 21, Julian day 202.

	ACCO 1014	Pioneer 8324	DeKalb F67	Millet
Hybrid average	79.8 b	89.7 a	93.0 a	87.6

Ashland Dryland

Dry matter, nitrogen, phosphorus and potassium uptake by sorghum and millet. Figure 4 and Tables A12-A19 show dry matter accumulation and nutrient uptake averaged over sorghum hybrids for the Ashland dryland study.

Like in the irrigated study, dry matter accumulation by sorghum (Fig. 4a) in the early stages was highest in alternate rows, changing

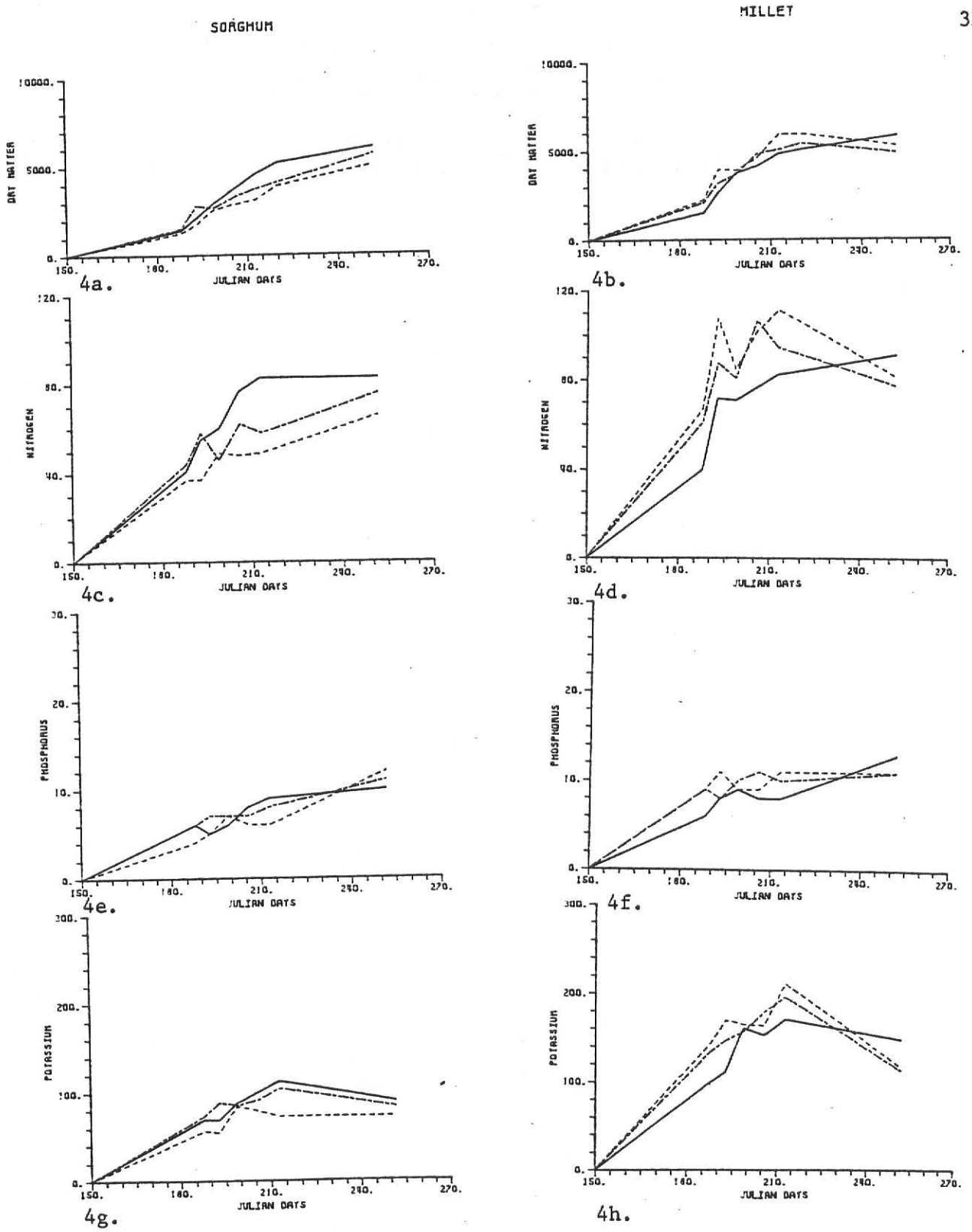

Figure 4. Dry matter and nutrient accumulation by sorghum and millet, averaged by cropping system, Ashland dryland.

about millet flowering (Julian day 197) to highest dry matter values for sorghum in sole stands (significant on Julian days 206, 213 and 220). During grain filling, sorghum in mixtures, especially in alternate rows, could compensate somewhat, resulting in no significant differences at physiological maturity, but still with highest values in sole stands. In contrast to the irrigated study, the curves for dryland are flattening out during grain filling, while curves under irrigation still have considerable slope during grain filling.

Like under irrigation, millet dry matter production (Fig. 4b) in within-row mixtures had a peak on Julian day 193, with significantly higher values for dry matter from within-row mixtures than from either sole stands or alternate rows. Millet, shortly before flowering, could compete with sorghum much more successfully than with plants of its own species, especially when planted in within-row mixtures, where the interfaces between sorghum and millet were largest.

Nitrogen uptake by sorghum (Fig. 4c) also behaved like under irrigation with highest values from millet flowering to physiological maturity in sole stands. However, the curve was flattening out earlier and did not reach the same maximum as sorghum under irrigation.

Millet nitrogen uptake (Fig. 4d) and phosphorus uptake (Fig. 4f) were significantly higher in within-row mixtures than in alternate rows only on Julian day 193. Sorghum phosphorus uptake (Fig. 4e) was much lower than under irrigation. Significant differences early in the season with highest values in sole stands (significant on Julian day 188) and alternate rows (significant on Julian day 193) leveled out later on.

Potassium uptake by sorghum was significantly highest in alternate rows on Julian day 193, but after millet flowering, had highest values in sole stands and alternate rows (significantly on Julian day 213) up to physiological maturity. Millet potassium uptake curves showed no significant differences over the whole growing period.

Curves for growth and nutrient uptake on dryland generally behaved like under irrigation. However, dry matter and phosphorus uptake curves of sorghum ceased earlier on dryland than under irrigation. Especially grain filling of the early and the medium sorghum was shortened due to severe drought stress. Drought stress in mixed sorghum and millet was even more severe than in sole sorghum, since millet was competing much more successfully for water, presumably due to higher K contents than sorghum (Mengel, 1979).

Figure 5 and Tables A13-A15 show growth and nutrient uptake curves by sorghum hybrids averaged over cropping systems.

Dry matter and nutrient uptake by sorghum was similar to that under irrigation, except that ACCO ceased growing earlier on dryland than under irrigation. Dry matter and nutrient uptake of millet followed the same trends as under irrigation. Only phosphorus uptake was much lower than under irrigation and increased considerably during grain filling when intercropped with ACCO.

Significant sorghum x cropping system interactions with sorghum could be found on Julian day 188 for P and K, and for dry matter on Julian day 220. Figure 6 a-f show dry matter accumulation of sorghum (6a ACCO, 6b Pioneer, 6c DeKalb) and the corresponding millets. Compared to the irrigated study, Pioneer and DeKalb on dry land did not

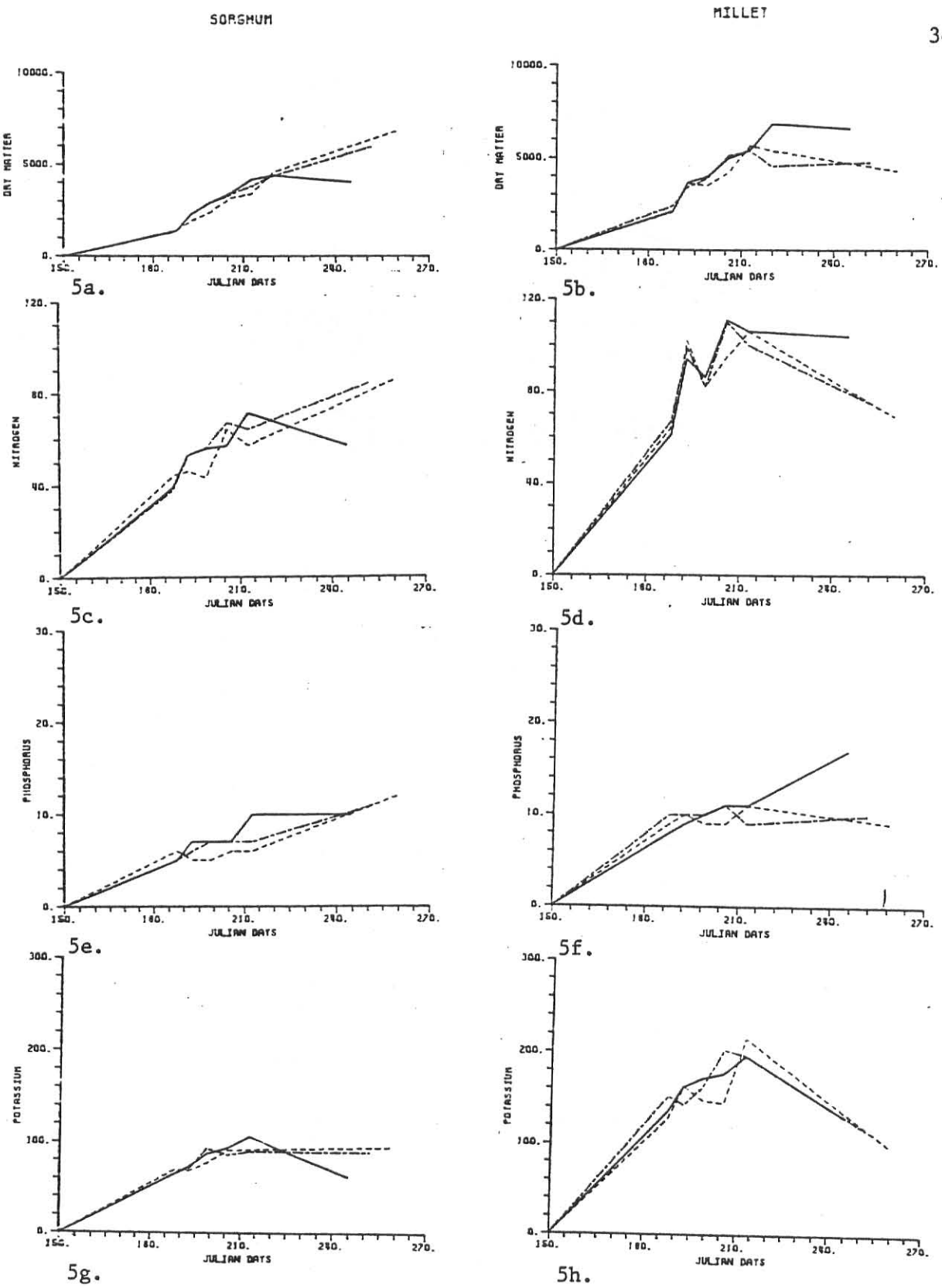

Figure 5. Dry matter and nutrient accumulation by sorghum and millet, averaged by sorghum hybrid, Ashland dryland.

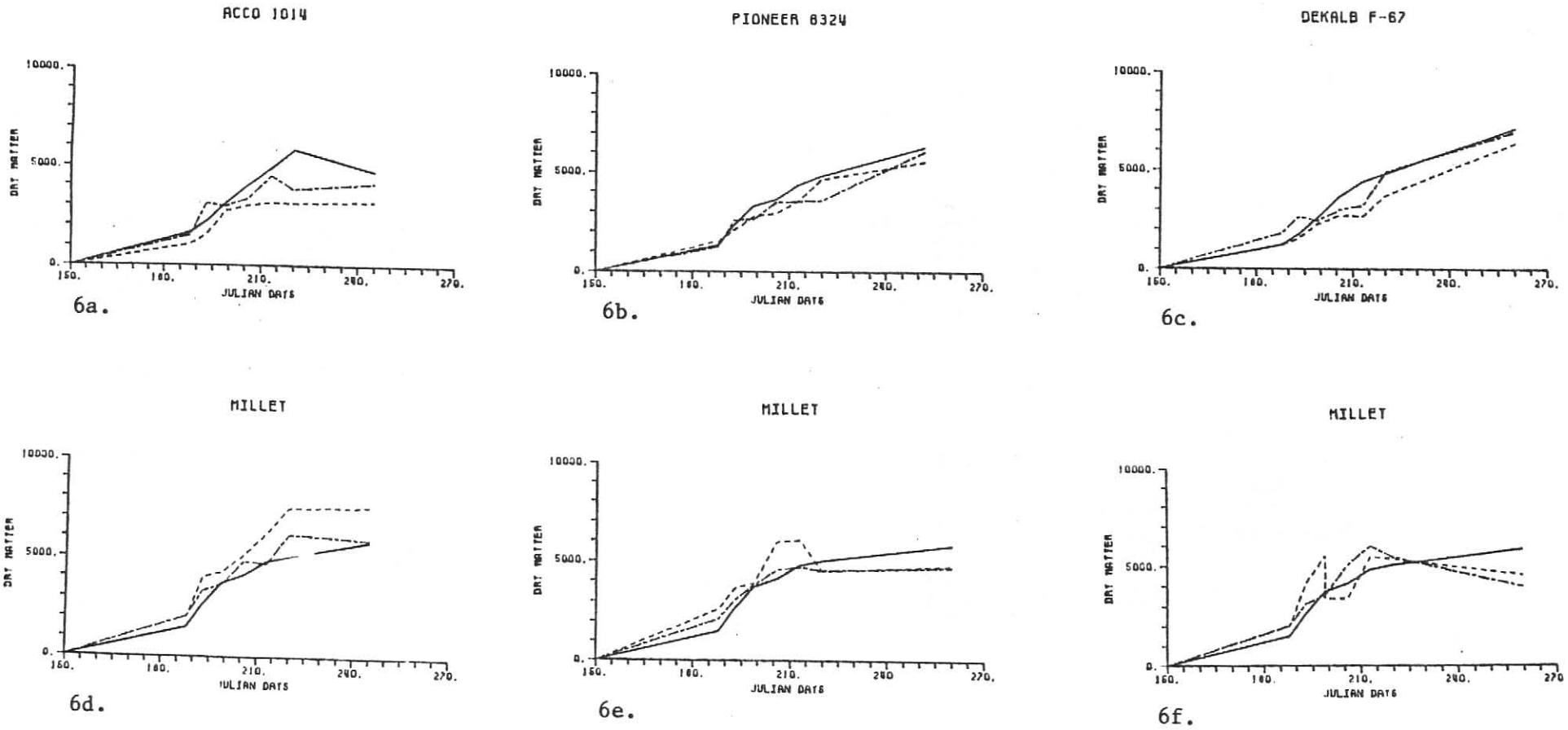

Figure 6. Dry matter accumulation of three sorghum hybrids and corresponding millet.

have the same increase in growth during grain filling, but were still able to compensate.

Especially ACCO in within-row mixtures had ceased growth by Julian day 206 and was only translocating photosynthates from then on. Like under irrigation, the complementarity of sorghum and millet can be seen. When millet growth was decreasing, sorghum growth accelerated.

Thus, the main differences between the dry land and irrigated studies regarding dry matter and nutrient accumulation were:

1. On dryland, significances between sorghum hybrids with respect to N and P uptake already occurred at flowering of millet and early sorghum, while under irrigation they developed from Julian day 213 on.
2. Generative development of the late sorghum was delayed on dryland due to drought stress until sufficient rain fell. Under irrigation, this delay was not observed.
3. Millet growth during grain filling was not dependent on cropping systems on dryland, whereas it was dependent on cropping systems under irrigation.
4. Compensation of the medium and the late sorghum hybrid during grain filling was much lower on dryland than under irrigation.

Total dry matter, nitrogen, phosphorus, and potassium accumulation. Dry matter production, N, and P uptake were significantly higher in mixtures than in sole stands of sorghum only on Julian day 193 (Table 5). After flowering of millet, no significant differences between

cropping systems could be found with respect to dry matter or N and P uptake. On Julian day 213, P accumulation was significantly higher in treatments with ACCO than in those with DeKalb and Pioneer; dry matter accumulation was significantly different only between ACCO and DeKalb.

Table 5. Total dry matter, nitrogen and phosphorus accumulation. Ashland dryland, Julian day 193.

Cropping system	dry matter	nitrogen	phosphorus
sole stand	4119.6 b	110.77 b	10.97 b
alternate rows	5941.6 a	146.46 a	15.52 a
within-row mixtures	5735.6 a	147.82 a	16.48 a

Potassium uptake by millet was generally higher than by sorghum, resulting in significant differences between mixtures and sole stands of sorghum (Table 6). On Julian day 199 and at physiological maturity of sorghum, sole stands of millet had accumulated significantly higher amounts of K than mixtures.

Table 6. Potassium uptake in total treatments.

	Julian day					
Cropping system	188	193	199	206	213	ph. mat.
sole millet	200.0	221.9	321.0*	304.2	341.0	293.6*
sole sorghum	137.4 b	136.8 b	175.9 b	199.3 b	223.4 b	178.1
alternate rows	222.5 a	234.9 a	241.1 a	274.3 a	302.4 a	198.6
within-row mixt.	199.4 a	227.7 a	248.7 a	250.0 a	282.3 a	193.6

Grain filling. Table A56 (analysis of variance for separated plant parts over both days) gives an overall view over the period from Julian day 220 to physiological maturity. Consistently for dry matter and K accumulation by vegetative sorghum parts, no significant differences occurred between the days. However, as expected, significant day x cropping system interactions showed up with respect to N and P uptake (Table 7), meaning that nitrogen and phosphorus uptake during this period was different among cropping systems. As mentioned above, sorghum took up more N and P as an intercrop than in sole stands. Significant differences showed up also between sorghum heads with respect to dry matter accumulation (Table 7) over this period. As described above, differences existed between sorghum hybrids DeKalb with more than 2500 kg/.5 ha dry matter accumulation between Julian day 220 and physiological maturity in the heads and Pioneer with not even 100 kg/.5 ha and ACCO with almost no dry weight increase.

Table 7. Nitrogen and phosphorus uptake of vegetative sorghum parts and dry matter accumulation in sorghum heads (kg/.5 ha), Ashland dryland.

	vegetative parts				heads	
	nitrogen		phosphorus		dry matter	
Cropping system	220	p.m.	220	p.m.	220	p.m.
sole stand	54 a	36	5.0 a	3.7	1534 a	2654
alternate rows	41 b	38	4.3 ab	5.1	921 b	1870
within-row mixtures	35 b	33	3.9 b	7.2	1044 b	1998

Table A57 shows significant differences between the two sampling dates only for vegetative parts of millet. Significant differences could be observed with respect to all parameters between the two days (Julian day 220 and physiological maturity). Only changes in phosphorus content were dependent on the sorghum hybrid intercropped with (Table 8).

Table 8. Phosphorus accumulation in millet vegetative parts (kg/.5 ha), Julian day 220 and at physiological maturity, Ashland dryland.

	P in vegetative parts	
Hybrid	220	p.m.
ACCO	5.5 a	8.8
Pioneer	4.3 b	4.7
DeKalb	5.1 ab	4.6

Canopy heights. Table 9 shows the dryland sorghum heights. The analysis of variance (Table A69) shows a significant sorghum x cropping system interaction which indicates that canopy heights did not behave equally in the different cropping systems. ACCO 1014 was about 10 cm taller in mixed rows than in sole stands or alternate rows, whereas only relatively small differences existed between cropping systems with the other sorghum hybrids. It seems that especially in mixtures, where sorghum is surrounded from almost all directions by millet plants, height adaptation occurred in order to get higher quantities of light.

Table 9. Sorghum heights (dryland) on July 21, Julian day 202.

Cropping system	ACCO 1014	Pioneer 8324	DeKalb F67	crop. system average
sole stand	70.0	87.0	88.5	81.8
alternate rows	69.5	91.0	87.5	82.6
within-row mixtures	80.3	87.8	88.0	85.3
hybrid average	73.3 b	88.6 a	88.0 a	

Millet canopy heights were not significantly different. They were generally in the range of the medium and late sorghum (85-92 cm). Part of the millet grain yield increase when intercropped with ACCO 1014 presumably was because millet was about 8-10 cm taller than ACCO and so was more competitive for light than when intercropped with Pioneer and DeKalb. Considering the higher competitivity for water as compared to sorghum and the resulting photosynthetic activity even under considerable levels of stress, high yield increases especially on dryland can be expected in mixtures with ACCO as compared to any other combination.

Grain Yields

Ashland Irrigated

Sorghum. Grain yields (kg/.5 ha) and yield components of sorghum are shown in Table 10.

Table 10. Sorghum grain yields (kg/.5 ha) and yield components, Ashland irrigated.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	
sole stand	3022.1	3211.6	2784.8	3006.2	grain yield/.5 ha (kg)
alternate rows	2244.3	3419.1	3266.4	2976.6	
within-row mixt.	2011.2	3486.6	3065.3	2854.4	
hybrid average	2425.9 c	3372.4 a	3038.9 b		
sole stand	.500	.500	.500	.500	(LER)
alternate rows	.396	.536	.620	.517	
within-row mixt.	.334	.545	.603	.494	
hybrid average	.401 b	.527 a	.574 a		
sole stand	85304	82882	78307	82165 a	head no. (.5 ha)
alternate rows	73463	71311	68889	71221 b	
within-row mixt.	79925	76693	69965	73195 b	
hybrid average	77231	76962	72387		
sole stand	35.53	38.83	35.57	36.64 b	grain yield/ head(g)
alternate rows	32.03	49.04	47.60	42.89 a	
within-row mixt.	27.51	45.52	43.92	38.98 ab	
hybrid average	31.39 b	44.47 a	42.36 a		
sole stand	1526.6	2027.6	1755.2	1769.8	seeds/ head
alternate rows	1360.0	2380.5	1960.9	1900.5	
within-row mixt.	1280.4	2224.9	1828.3	1777.9	
hybrid average	1389.0 c	2211.0 a	1848.1 b		
sole stand	20.38	17.00	18.63	18.67	1000 seed weight(g)
alternate rows	20.69	18.00	21.25	19.98	
within-row mixt.	18.81	17.94	21.00	19.25	
hybrid average	19.96 a	17.65 b	20.29 a		

Average values with the same or no letter are not significantly (5% level) different.

Grain yields were highest (significantly) from the medium hybrid, followed by the late and the early hybrids. The medium sorghum, Pioneer 8324, had highest grain yield per head as a result of highest seed number per head, and second highest (not significant) number of heads per half hectare, which both contributed to the significant grain yield advantage over the other hybrids, although thousand seed weight was significantly lower than either of the other hybrids. The late hybrid had lower grain yield per head and number of heads per half hectare (both not significant) resulting in significantly lower grain yield per half hectare than the medium hybrid. Significantly lower number of seeds per head than the medium was compensated for by significantly higher thousand seed weight. The early hybrid had significantly lowest grain yield, although it had highest number of heads per half hectare (nonsignificant). Grain yield per head was significantly lower than either of the other hybrids, as a result of significantly lowest number of seeds per head, which could not be compensated for by high thousand seed weight.

Looking at grain yields on an LER basis, the medium and the late sorghums were not significantly different, although the late one was highest, i.e. had highest intercropping advantage. Both were higher than 0.5, indicating that both sorghums in both intercropping treatments outyielded sole stands. This was not the case with the early hybrid, showing lower values in both intercropping treatments than in sole stands (significant sorghum x cropping system treatment).

Sole stands had consistently and significantly higher head numbers per half hectare, with a slightly, but not significantly higher number

in within-row mixtures than in alternate rows. Since the number of heads was an indication of the number of tillers, it can be concluded that tillering was favored by sole stands. Significantly highest grain yield per head was obtained from alternate rows, followed by mixed rows and sole stands. This was the case for the average over all three hybrids and for Pioneer and DeKalb. ACCO had highest yields in sole stands, followed by alternate rows and within-row mixtures. This explains the significant sorghum x cropping system interaction and was mainly a result of numbers of seeds per head which showed exactly the same trend. It can be concluded, therefore, that either pollination was best in alternate rows or, more likely, that during or a little after growing point differentiation of sorghum, more floral primordia were produced (or, already produced ones were aborted in other cropping systems). This seems logical since sorghum had best growth during that time in alternate rows.

To get an idea of yield changes due to cropping systems, it makes more sense to look at the relative values, the grain yield values on an LER basis. Interspecific competition was higher than intraspecific competition, regardless of the cropping system, with ACCO 1014, which had almost the same growth cycle as millet. The opposite was observed with the two other hybrids. Yield advantages due to intercropping were higher with the late than the medium hybrid, supporting the hypothesis that yield increases relative to sole stands are a function of temporal differences between the intercropped components. Cropping systems did not influence yields significantly, since differences in grain yields per head between cropping systems and number of heads per half hectare

level each other. Relative yield increase of the medium and late sorghum as intercrops were because of higher thousand seed weights and higher seed numbers per head as compared to sole stands. Especially the higher thousand seed weights were a result of lower competition by millet during grain filling than through plants of the same species. ACCO, however, had lower intercrop yields as compared to sole stands as a result of lower values for all yield components with the exception of thousand seed weight in alternate rows.

Millet. No significant differences occurred among cropping systems (Table A66). Grain yields, LER, grain yield/head and seed weight were dependent on the sorghum hybrid intercropped with (Table 11).

Cropping systems with ACCO 1014 yielded significantly higher than those with DeKalb or Pioneer. This was due to significantly higher head numbers and thousand seed weights. Grain yields per head and number of seeds per head were not significantly different. Thousand seed weight was highest in combinations with ACCO because of less competition during grain filling than in combinations with DeKalb or Pioneer, which had maximum demands during grain filling of millet and presumably shaded the millet plants more than ACCO due to significantly greater plant height. Higher thousand seed weight and heads per half hectare both contributed to the relatively higher millet grain yields on an LER basis when intercropped with ACCO than in sole stands. Conversely, they were numerically lower when intercropped with DeKalb and Pioneer. Although not significant, it is remarkable that millet gave

Table 11. Millet grain yields (kg/.5 ha) and yield components, Ashland irrigated.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	
sole stand				1876.7	grain yield/.5 ha (kg)
alternate rows	2013.7	1801.8	1862.6	1892.7	
within-row mixt.	2272.4	1665.9	1502.7	1813.6	
hybrid average	2143.1 a	1733.9 b	1682.6 b		
sole stand				.500	(LER)
alternate rows	.540	.481	.498	.506	
within-row mixt.	.602	.447	.401	.483	
hybrid average	.571 a	.464 b	.449 b		
sole stand				123785	head no. (.5 ha)
alternate rows	149887	129436	129704	136343	
within-row mixt.	148004	124323	116519	129612	
hybrid average	148946 a	126880 b	123112 b		
sole stand				15.46	grain yield/ head(g)
alternate rows	13.51	13.98	14.39	13.96	
within-row mixt.	15.35	13.45	13.05	13.95	
hybrid average	14.43	13.72	13.72		
sole stand				1179.4	seeds/ head
alternate rows	991.9	1069.8	1121.8	1061.1	
within-row mixt.	1109.9	1007.7	999.9	1039.2	
hybrid average	1050.9	1038.7	1060.9		
sole stand				11.50	1000 seed weight(g)
alternate rows	11.95	11.43	11.23	11.53	
within-row mixt.	12.15	11.70	11.40	11.75	
hybrid average	12.05 a	11.56 b	11.31 b		

Average values with the same or no letter are not significantly (5% level) different.

highest yields when intercropped with ACCO in within-row mixtures and lowest in sole stands. The opposite was the case with millet intercropped with DeKalb and Pioneer. Number of millet heads per half hectare were, not significantly, but consistently, highest in alternate rows with all three sorghums. This matches with the sorghum head numbers, which were significantly lowest with all three hybrids in alternate rows, indicating a certain complementarity between sorghum and millet and higher competitivity of millet with respect to number of heads.

Since millet heights were the same with all sorghums and in all cropping systems, but ACCO heights were significantly lower than those of DeKalb and Pioneer, millet had a competitive advantage when intercropped with ACCO with respect to light interception. At least in part, increase in millet grain yields when intercropped with ACCO may be due to that fact.

Total grain yields (sorghum + millet). Significant differences (Table A68) could be found among cropping systems. Sole stands of sorghum yielded significantly more grain (23-28%) than mixtures, which yielded significantly more grain (24-30%) than sole stands of millet (Table 12). These differences were mainly a result of the different yield levels of sorghum and millet. Lower yields of the intercrops compared to sole sorghum or higher yields of the intercrops compared to sole millet were not necessarily a result of positive or negative intercropping effects.

Grain yields in treatments with ACCO and DeKalb were significantly (more than 10%) lower than in treatments with Pioneer (Table 12).

Table 12. Total grain yields (sorghum + millet) in kg/ha, Ashland irrigated.

Hybrid	Yield, kg/ha	Cropping System	Yield, kg/ha
ACCO 1014	4861.9 b	sole stand-sorghum	6012.4 a
Pioneer 8324	5598.9 a	alternate rows	4869.3 b
DeKalb F67	5088.9 b	within-row mixtures	4668.0 b
millet	3753.3	sole stand-millet	3753.0

Looking at yields on an LER basis, all significant differences disappear (Table A23). All treatments yielded fairly close to 1.0 on an LER basis, meaning that no positive or negative intercropping effects occurred. So, one hectare of sorghum and millet intercropped would yield as much grain as half a hectare of sorghum plus half a hectare of millet in sole stands.

Ashland Dryland

Sorghum. Table 13 shows grain yields and yield components of sorghum under dryland conditions at Ashland.

Grain yields produced by DeKalb were significantly highest, over all cropping systems, as a result of highest (nonsignificant) plant populations and yields per head were significantly higher than either of the other hybrids. Highest grain yields per head were a result of highest (nonsignificant) seed number per head and (significantly) highest thousand seed weight. ACCO and Pioneer grain yields were significantly lower than those obtained from DeKalb F67, but not

Table 13. Sorghum grain yields (kg/.5 ha) and yield components, Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	
sole stand	1621.6	1854.4	2060.4	1845.5 a	grain yield/.5 ha (kg)
alternate rows	965.0	657.3	1427.5	1016.6 b	
within-row mixt.	860.5	888.0	1050.5	933.0 b	
hybrid average	1149.0 b	1133.3 b	1512.8 a		
sole stand	.500	.500	.500	.500 a	(LER)
alternate rows	.297	.203	.353	.284 b	
within-row mixt.	.270	.281	.256	.269 b	
hybrid average	.356	.328	.370		
sole stand	72118	70773	72387	71759 a	head no. (.5 ha)
alternate rows	47630	43593	57317	49514 b	
within-row mixt.	58932	52204	51667	54268 b	
hybrid average	59560	55524	60457		
sole stand	22.64	26.55	28.44	25.87 a	grain yield/ head(g)
alternate rows	19.59	14.55	24.22	19.45 b	
within-row mixt.	14.82	16.26	20.45	17.18 b	
hybrid average	19.02 b	19.12 b	24.37 a		
sole stand	1110.5	1377.0	1420.2	1302.6 a	seeds/ head
alternate rows	949.5	686.5	1053.3	896.4 b	
within-row mixt.	936.0	738.5	866.0	846.9 b	
hybrid average	998.7	934.0	1113.2		
sole stand	17.81	16.50	17.63	17.31 b	1000 seed weight(g)
alternate rows	17.88	18.81	20.38	19.02 a	
within-row mixt.	14.00	19.25	20.75	18.00 ab	
hybrid average	16.56 c	18.19 b	19.58 a		

Average values with the same or no letter are not significantly (5% level) different.

significantly different from each other, as were yield components, with the exception of thousand seed weight, which was not significantly different between Pioneer and ACCO. Pioneer and DeKalb had highest thousand seed weights in within-row mixtures and lowest in sole stands. ACCO had highest seed weights in alternate rows and lowest in within-row mixtures (significant sorghum x cropping system interaction). With the exception of thousand seed weight, sole stands had highest values for yields and yield components. They were significantly lower in intercrops than in sole stands but not significantly different between intercrops.

Grain yields on an LER basis were not significantly different among hybrids, but, here too, cropping systems were significantly lower than sole stands. The results have to be considered under the aspect of mid-summer drought. Millet was undoubtedly more competitive with respect to water than sorghum, i.e. sorghum plants suffered more from competition by millet than by plants of their own species. The two earlier hybrids suffered more from drought stress; DeKalb just ceased growth and exerted heads after sufficient rainfall. Most damaged was Pioneer, which could not exert heads completely. Pollination was decreased, especially in the intercrops, resulting in lowest seed numbers per head. ACCO had already completed a larger part of its life cycle when stress became severe. The two later hybrids could compensate for the drought at least partly through better filling of the remaining grains, resulting in higher thousand seed weights in intercropped sorghum, especially in within-row mixtures than in sole

stands. Here again, the importance of lack of interspecific competition during parts of grain filling can be seen.

Millet. No significant differences in millet yields or yield components were found (Table A67). However, many of the same trends were found as in the irrigated study.

Total grain yields (sorghum + millet). Table 14 shows total grain yields (sorghum + millet) in kg/ha for all treatments. Significant differences (Table A68) could be observed between cropping systems. Sole stands of sorghum yielded significantly more grain (ca. 100%) than either alternate row or within-row mixtures. Sole stands of millet, however, were not significantly lower than mixtures.

Table 14. Total grain yields (kg/ha), Ashland dryland.

Cropping System	Yield, kg/ha
sole stand-sorghum	3690.9 a
alternate rows	1837.5 b
within-row mixtures	1824.4 b
sole stand-millet	1464.2

On an LER basis, no significant cropping system differences were found. Sorghum hybrids did not significantly affect grain yields on either an absolute or an LER basis. In contrast to the irrigated study, where treatments with Pioneer had significantly higher yields than those with ACCO and DeKalb, hybrids had no significant effect on

dryland yields. Increased competition between sorghum and millet for water in the dryland study damaged sorghum more than it favored millet, resulting in yield differences of about 100% between mixtures and sole stands of sorghum. Intercrop yields were not (in contrast to the irrigated study) significantly different from millet sole stand yields.

Grain Yields and Yield Components, Ashland

Effect of water stress. The influence of water stress on crops and cropping systems were evaluated by comparison of irrigated and non-irrigated studies (Table A71).

Sorghum. Grain yields and yield components were significantly different (except thousand seed weight) between dryland and irrigated studies. It was to be expected that plants under irrigation (due to better water and nutrient supply) produced more heads, as a consequence of higher tillering, and more seeds per head, as a result of better pollination or less abortion of floral primordia. The fact that no differences with respect to thousand seed weight were found can be explained with relatively favorable conditions during grain filling and lower seed numbers in the dryland study. However, under dryland conditions, thousand seed weight was significantly lower with ACCO 1014 than with either of the other hybrids, whereas it had (together with DeKalb) highest values in the irrigated study (significant water x sorghum interaction). This was because a large part of ACCO's grain filling was during mid-summer drought and increased competition by millet.

No significant differences could be observed between sorghum hybrids with respect to seed number per head in the dryland study. In the irrigated study, however, Pioneer had highest and DeKalb and ACCO significantly lower seed number per head (significant water x sorghum interaction) (Figure 7). Under dryland conditions, cropping systems had significantly different influence on sorghum with respect to seed number per head, with highest numbers in sole stands and significantly lower values in the intercrops. No differences occurred, in contrast, with irrigation (significant sorghum x cropping system interaction). With all hybrids, highest values for seed number per head on dryland occurred in monocultures and lowest in within-row mixtures (Pioneer:alternate rows). Under irrigation, only ACCO had highest seed numbers in monocultures, whereas Pioneer and DeKalb performed best in alternate rows, followed by within-row mixtures (significant sorghum x cropping system x water interaction).

It can be seen in Figure 8 that under dryland conditions, interspecific competition with respect to seed set was higher than intraspecific competition with all three hybrids. Temporal differences obviously did not play any significant role from a certain level of stress on. The medium sorghum which had highest grain yields per head (not significantly different from DeKalb) under irrigation had yields per head significantly lower than DeKalb and not significantly different from ACCO under dryland conditions (significant water x sorghum interaction) as a result of significantly lower thousand seed weight and numerically lower seed numbers per head than DeKalb, i.e. as a result of stress especially during pollination. As with the component seeds

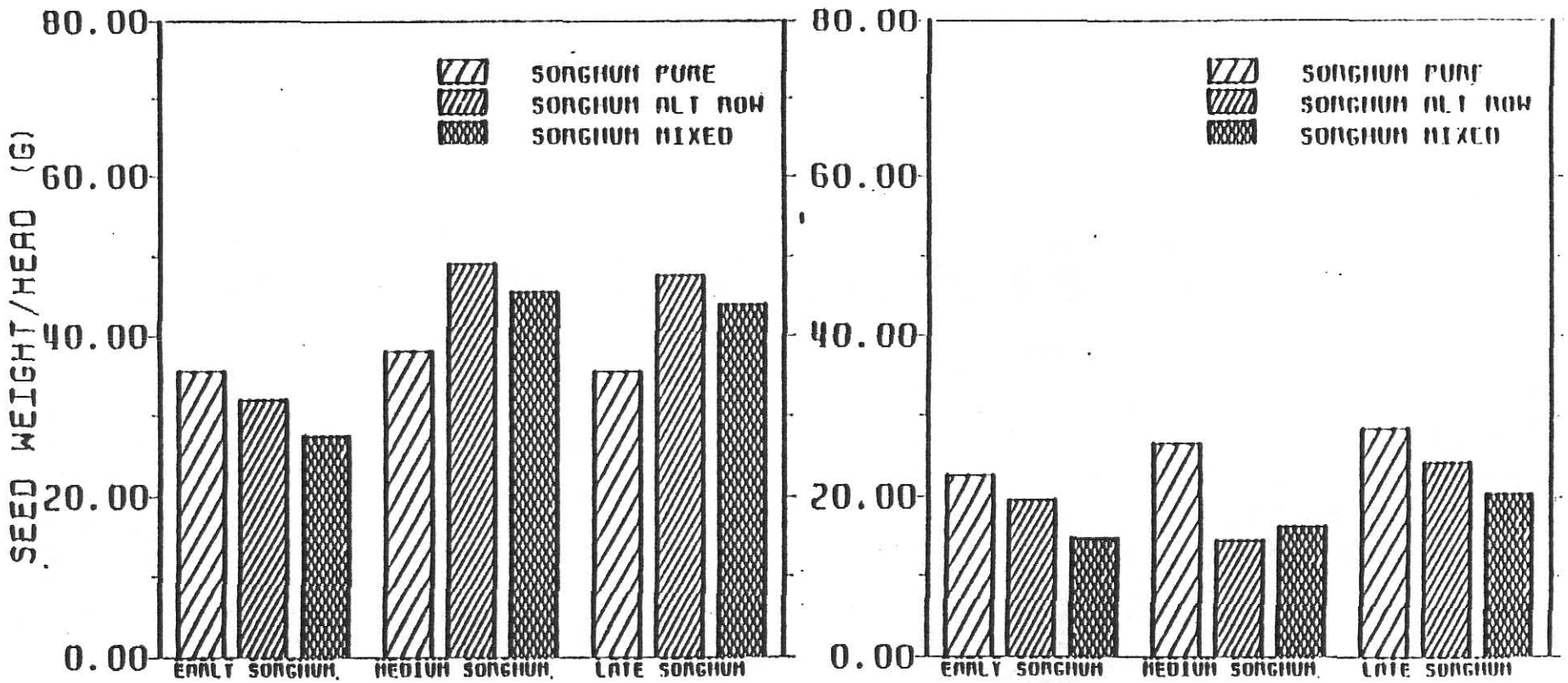

Figure 7. Sorghum grain yields per head under irrigation (left) and on dryland (right).

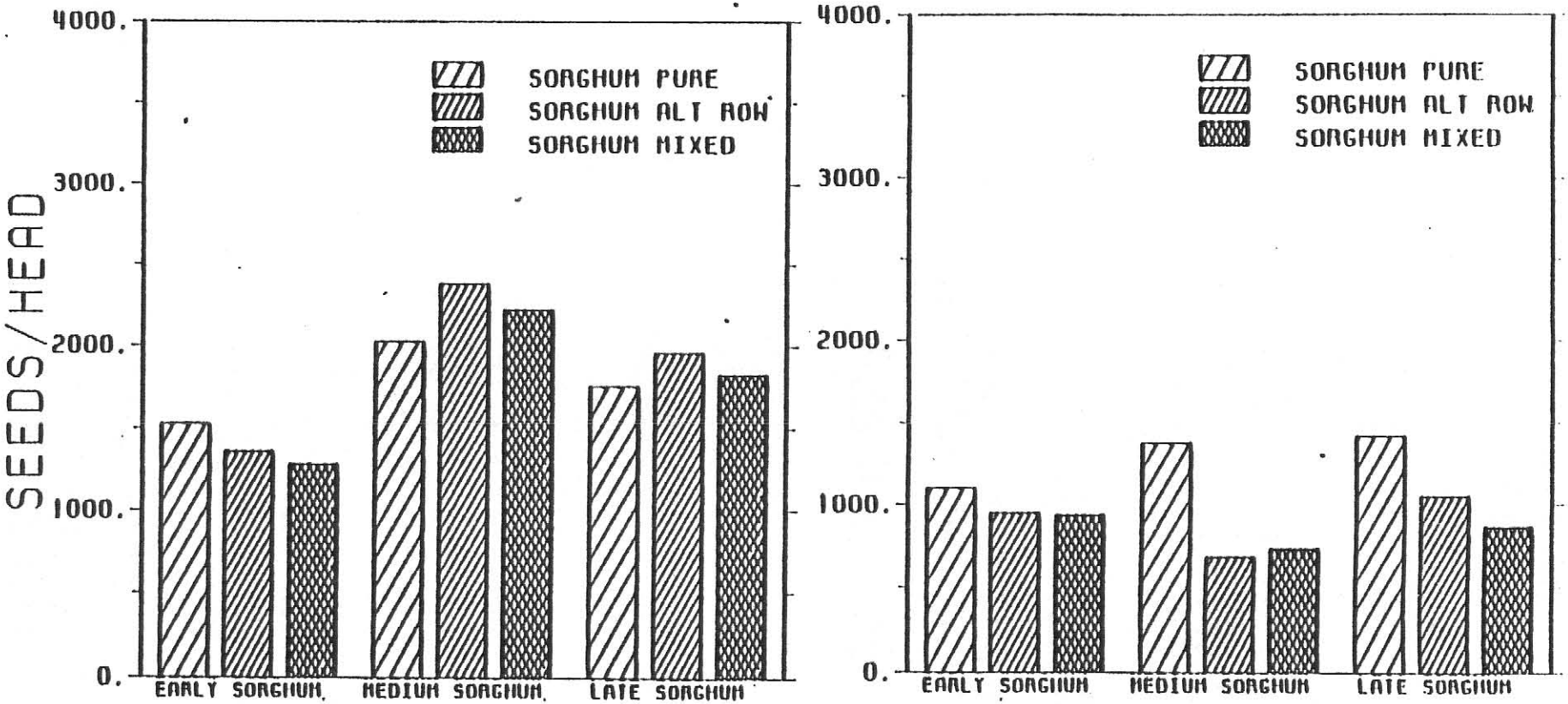

Figure 8. Sorghum seed numbers per head under irrigation (left) and on dryland (right) at Ashland.

per head and as a result of it, grain yield per head was significantly higher in monocultures than in intercrops without irrigation, but highest (significantly) in alternate rows (followed by within-row mixtures) under irrigation (significant water x cropping system interaction).

As with seeds per head, grain yield per head was highest in monocultures with all hybrids under dryland conditions, but only ACCO had highest grain yields per head in monocultures under irrigation, whereas DeKalb and Pioneer had highest grain yields per head in alternate rows and lowest in sole stands under irrigation (significant sorghum x cropping system x water interaction).

The number of sorghum heads per half hectare was significantly different depending on if irrigated or not, but did not interact with cropping systems or sorghum hybrids or both. Interactions between sorghum hybrids and water regime and cropping system and water regime with respect to grain yields per half hectare were therefore mainly a consequence of the interactions with respect to grain yield per head. Like with grain yield per head, grain yield per half hectare under irrigation was highest with the medium hybrid, followed by late DeKalb and ACCO. On dryland, grain yields were highest with DeKalb, which had better conditions during its generative phase than either of the other hybrids, followed by Pioneer and ACCO (significant water x sorghum interaction). Pioneer decreased under water stress conditions compared to adequate water supply, mainly because it flowered when water stress was most severe (decrease in seed number per head by more than 50% compared to irrigation). Under irrigation, no significant differences

could be observed between cropping systems with respect to grain yield per half hectare, but under dryland conditions monocultures yielded significantly higher values (significant water x cropping system interactions) than intercrops. While grain yield per half hectare in the dryland study was highest with all hybrids in monoculture, only ACCO had highest values in monoculture in the irrigated study. Pioneer and DeKalb had lowest yields in monoculture and highest in within-row mixtures and alternate rows, respectively (significant sorghum x cropping system x water interaction).

Looking at grain yields on an LER basis, no significant differences could be observed between sorghum hybrids on dryland, but under irrigation, Pioneer and DeKalb had significantly higher yields than ACCO (significant water x sorghum interaction). On the other hand, while no significant differences between cropping systems could be observed in the irrigated study, clear significant differences could be observed between monocultures (high) and intercrops (lower) on dryland (significant water x cropping system interaction). That means on dryland, intercropped sorghum performed significantly poorer than in sole stands, while the relationship under irrigation was more heterogenous.

Millet. Millet grain yields and yield components were significantly higher under irrigation than on dryland. However, differences between grain yields on an LER basis did not differ significantly. Regardless of the sorghum intercropped with or the cropping system, millet generally behaved equally under both water conditions. Only

with respect to thousand seed weight did significant water x sorghum interactions occur, i.e. thousand seed weight of millet was significantly higher intercropped with ACCO than when intercropped with Pioneer or DeKalb under irrigation, whereas no significant differences could be found regarding intercropping partners without irrigation. It can be seen that millet does not suffer from moisture stress as much as sorghum, i.e. it is more competitive for water than sorghum. Especially when intercropped with sorghum with the same growth cycle, ACCO 1014, the yield difference between cropping systems on an LER basis was much higher on dryland than under irrigation.

Summary: Effect of water stress on sorghum and millet. Differences between dryland and irrigation were significant with sorghum for grain yields and all yield components except thousand seed weight. Thousand seed weight was determined late in the season when water conditions were better on dryland again and competition by millet was lower. Competition by millet was much more severe on dryland than under irrigation, resulting in superiority of monocultures with respect to grain yield and all yield components except thousand seed weight on dryland, whereas under irrigation, monocultures were only superior over mixtures with ACCO, which had about the same life cycle as millet and therefore suffered most from millet competition. Under dryland conditions, grain yields and yield components were mainly dependent on cropping system, resulting in, with the exception of thousand seed weight, highest values for monocultures. Under conditions where water was presumably not, or only during short periods,

limiting genetic differences between sorghum hybrids could appear more clearly, and yields did not significantly depend on cropping systems. It can be seen that increasing stress increases competition for the limiting factor and increases the relative advantage for the component with the higher competitivity, millet in this case. Although millet yields and yield components decreased significantly under water limiting conditions, it was equally competitive with respect to all sorghum hybrids. However, only one combination gave grain yields on an LER basis greater than 1 under dryland conditions, indicating that millet not even on an LER basis could make up for the reduction of sorghum yields due to millet competition.

Grain Yields and Yield Components, Garden City

Grain yields and yield components of sorghum are shown in Table 15. No significant differences between cropping systems were observed. Sorghum hybrids, however, differed significantly in grain yields, head numbers, grain yields per head and seeds per head. Pioneer and ACCO had significantly higher values for all these parameters than DeKalb. Low yields of DeKalb (maximum of 391 kg/ha) were a result of low head numbers and poor seed set (resulting in low grain weight per head). In alternate rows, no significant amounts of grain could be harvested with DeKalb. Grain yields on an LER basis were significantly higher from ACCO than from Pioneer and DeKalb. ACCO performed better as an intercrop than as a sole crop (LER > .5), whereas Pioneer and DeKalb suffered more from millet competition than from competition from the same species. Seed number per head was about the same in all three cropping

systems with ACCO, but Pioneer and DeKalb showed much lower values in alternate rows than in the other cropping systems (significant sorghum x cropping system interaction). The number of heads per half hectare, in contrast, was highest in alternate rows as compared to the other cropping systems with ACCO and Pioneer, whereas DeKalb had almost no heads in alternate rows (significant sorghum x cropping system interaction). Thousand seed weight, although numerically lowest with DeKalb, did not differ significantly among sorghum hybrids.

Table 15. Sorghum grain yields (kg/.5 ha) and yield components, Garden City.

	grain yield/.5 ha		head no.	grain yield/ head	seeds/ head
	(kg)	(LER)	(.5 ha)		
ACCO 1014	1022.0 a	0.63 a	30,364 a	33.66 a	1409 a
Pioneer 8324	929.6 a	0.36 b	31,787 a	31.51 a	1169 a
DeKalb F67	199.5 b	0.33 b	16,526 b	11.34 b	517 b

It was shown in the Ashland experiment that during the early stages of development, alternate rows were most favorable for sorghum. This can be seen for ACCO and Pioneer in Garden City. They both produced more head bearing tillers during the early stages in alternate rows as compared to within-row mixtures and sole stands. Why DeKalb did not do so cannot be explained.

Millet grain yields and yield components are shown in Table 16. Neither grain yields nor yield components depended significantly on

the sorghum intercropped with. Head numbers were significantly higher in alternate rows than within-row mixtures. Sole stands were not significantly different from either mixture.

Table 16. Total grain yields, Garden City.

	Yield, kg/ha	LER
sole stand-sorghum	1466.0 a	
alternate rows	851.7 b	
within-row mixtures	902.5 b	
sole stand-millet	517.7	
ACCO 1014	1504.3 a	1.05 a
Pioneer 8324	1551.1 a	0.87 ab
DeKalb F67	480.0 b	0.69 b

Due to severe drought in Garden City, unequal stands developed and caused considerable variation of the data, resulting in few significances. A general statement is therefore hard to make. However, it seems that like in Ashland, the water stress made sorghum suffer more than millet. Millet, on the other hand, was not able to take advantage of this situation. By and large, cropping systems did not have any significant influence on yields, but mixtures seemed to reduce yields rather than to increase them compared to sole stands. This agrees with the observations in Ashland under water stress conditions.

Total grain yields on absolute basis (sorghum + millet) per hectare were significantly dependent on cropping systems. Sole stands of sorghum had significantly higher yields than either of the mixtures. Sole stands of millet were not significantly different from mixtures. Yields of treatments with ACCO and Pioneer had significantly (three times) higher yields than DeKalb on an absolute basis. Cropping systems did not influence the yields on an LER basis, although mixtures were numerically lower than sole stands. Mixtures with DeKalb had significantly lower yields on an LER basis than those with ACCO. Pioneer was not significantly different from either of the other hybrids.

Basically, the same observations could be made as at Ashland. Intercrop and sole millet yields were significantly lower than sole sorghum yields. On an LER basis, no significant differences could be found, although mixtures tended to be lower than sole stands (LER < 1) like in Ashland on dryland. It seems the drier conditions are, the lower intercropping yields on an LER basis tend to be. Low yields of treatments with DeKalb were a result of low yields of DeKalb itself which were even lower in mixtures than in sole stands.

Grain Yields and Yield Components, St. John

Sorghum grain yields (Table 17) were significantly dependent on cropping systems. They were highest in sole stands, followed by within-row mixtures and alternate rows. The same order was observed for head numbers and thousand seed weight. Grain yield per head and seed number per head showed no significant differences with respect to cropping systems.

Table 17. Sorghum grain yields (kg/.5 ha) and yield components, St. John.

	grain yield/.5 ha (kg)	(LER)	head no. (.5 ha)	grain yield/ head	seeds/ head	1000 seed weight
ACCO 1014	442.5 b	0.38	58,712 a	7.82 b	291 b	24.1
Pioneer 8324	800.6 a	0.43	38,598 b	20.45 a	767 a	23.4
DeKalb F67	949.7 a	0.39	39,250 b	24.05 a	864 a	24.0
sole stand	917.4 a	0.50	47,948 a	21.13	701	26.2 a
alternate rows	556.4 b	0.32	42,621 b	13.76	528	22.5 b
within-row mixt.	744.1 ab	0.39	45,991 ab	18.30	729	22.8 b

Grain yields on an LER basis were not significantly dependent on cropping systems, although all mixtures had numerically lower LER values than 0.5. Treatments with DeKalb and Pioneer had significantly higher grain yields on an LER basis than ACCO, mainly as a result of significantly higher grain yield per head, which resulted from significantly highest seed number per head. Thousand seed weight did not differ significantly between sorghum hybrids, but head numbers were significantly higher with ACCO than with the two later hybrids. ACCO obviously had better growing conditions during its vegetative development (tillering) than the other hybrids. However, during the late vegetative stages or during flowering, losses of floral primordia or insufficient pollination must have taken place with ACCO, resulting in low seed numbers per head.

With respect to cropping systems, no new results were found compared to the other locations. Sole stands yielded highest and had highest head numbers. However, sorghum in mixtures did not compensate for lower head numbers and seed numbers with higher thousand seed weight. This was probably because millet continued growing and producing heads when the first heads were already at the end of grain filling. Drought in mid-summer, but rainfall during grain filling, which made the nitrogen sidedressed in summer available, may have caused this. Thus, no real competition free period was available for the late sorghums in mixtures to compensate for the earlier millet competition.

The high production of millet heads can be seen in Table 18. This was more or less the case when intercropped with all sorghum hybrids and in all cropping systems. Grain yield did not depend on cropping systems nor on sorghum hybrids intercropped with. Only thousand seed weight showed significant differences. It was significantly higher in within-row mixtures than in sole stands or alternate rows. It was also significantly higher when intercropped with Pioneer than with DeKalb or ACCO. However, significantly higher thousand seed weights did not result in significantly higher grain weights per head nor higher yields per half hectare.

Total grain yields in kg per hectare essentially followed the same trends as sorghum yields. This was not surprising since no significant differences among millet yields could be found. Thus, total yields were significantly higher in sole stands of sorghum than in alternate rows and numerically higher than in within-row mixtures. No significant

differences could be found between sole millet and intercrops with respect to total yield. Sole millet yields were also not significantly different from sole sorghum yields. St. John was the only location where this was the case.

Table 18. Total grain yields, St. John.

Hybrid	Yield, kg/ha	Cropping System	Yield, kg/ha
ACCO 1014	1213.7 b	sole stand-sorghum	1814.9 a
Pioneer 8324	1628.1 a	alternate rows	1316.7 b
DeKalb F67	1852.1 a	within-row mixtures	1572.3 ab
		sold stand-millet	1755.5

Total yields on an LER basis were numerically, but not significantly lower with both mixtures compared to sole crops of sorghum and millet. As mentioned above, sorghum and millet yielded consistently, but not significantly lower in mixtures than in sole stands. It must be assumed that no real temporal differences existed between sorghum and millet (due to secondary heading) and so no period free from interspecific competition existed for either sorghum or millet and both grain filling periods were essentially identical.

CONCLUSIONS

Effects of Cropping Systems

Significant differences between cropping systems existed mainly between sole stands of sorghum and mixtures. With respect to grain yields of the components as well as of total yields, no significant differences existed between within-row mixtures and alternate rows. At all locations, total grain yields of sole sorghum were significantly higher than at least one of the mixtures. Millet grain yields at all locations were not significantly dependent on cropping systems. Millet was more competitive for water, presumably due to higher K contents compared to sorghum, so whenever moisture conditions were severely limiting, sorghum yields in mixtures were reduced significantly compared to sole stands as it was in the dryland studies at Ashland, St. John, and Garden City.

In the early stages, both crops tended to grow better in mixtures. When maximum nutrient and water demands as well as maximum LAI were reached (around millet flowering), competition became more severe. The competitive ability of millet could be observed in higher dry matter and nutrient accumulation of millet in mixtures as compared to sole millet over large parts of the growing season. Sorghum growth and nutrient uptake tended to be lower in mixtures during the main growing season than in sole stands. However, where water was less limiting,

intercropped sorghum was not affected as adversely compared to sole stands, as under severe drought stress.

Thus, the main effects of cropping systems consisted of competition between crops for limiting growth factors, mainly water. Although millet was competing more successfully and could compensate for the decrease of sorghum in terms of biomass production, it could not do so in terms of grain yields.

Effects of Sorghum Hybrids

Generally, the early hybrid, which had a growth cycle almost identical with millet, had lowest growth and nutrient uptake, due to most direct competition with millet. Especially from flowering on, when competition with millet was most intensive, growth of ACCO (absolute grain yields and on an LER basis) was substantially reduced by millet. Thus, grain yields of the early sorghum were significantly lowest at Ashland under irrigation and at St. John, and together with the medium hybrid, at Ashland on dryland; whereas at Garden City the early hybrid yielded highest. Total grain yields, as influenced substantially by the yield of the higher yielding component (sorghum), behaved the same way. Only under irrigation at Ashland did sorghum hybrids have a significant influence on millet yields, which were significantly highest intercropped with the early hybrid.

Sorghum x cropping system interactions with respect to grain yields occurred (except at Garden City due to complete failure of DeKalb in alternate rows) only under irrigation. Whereas growth of the early sorghum in mixtures was below sole stands throughout grain filling,

Pioneer and especially DeKalb could compensate for millet competition during grain filling, especially after maturity of millet. This shows the importance of freedom from interspecific competition during grain filling in polyculture systems particularly when growing conditions are favorable enough to permit compensative growth.

Use of Growth Factors and Productivity of Sorghum/Millet Intercrops

In terms of grain yields, mixtures were significantly lower than sole stands of sorghum at all locations, mainly because of the lower yield potential of millet compared to sorghum. On an LER basis, no significant differences could be found between mixtures and sole sorghum. Yield increases of mixtures on an LER basis, as frequently described in the literature, could not be found. The relatively small differences in growth cycles did not influence yields significantly. Growth curves indicated that if a period free from interspecific competition exists, the component still growing was able to make use of improved conditions as long as limiting growth factors permitted. Freedom from competition was especially important during the generative stage. It seems very likely that intercrop yield increases could have been obtained if sorghum had had a longer period free from interspecific competition during grain filling. Traditional intercropping system advantages are obtained that way. An equation presented by Baker and Norman (1975) indicated that at least 35 days of difference in growth cycles between crops must exist in order to get yield increases relative to sole stands.

Are sorghum/millet intercrops more productive than sole stands at optimum population densities if yield increases require longer use of the productive area? The LER concept does not take this into account. Therefore, a parameter "land equivalent productivity" is proposed which allows judgments regarding the efficiency of use of the land. The land equivalent productivity would be the sum of the LER's for the individual components multiplied by the time sole crops would occupy the area and divided by the time the field is actually occupied until the latest crop is harvested.

$$\text{Land equivalent productivity} = \frac{\Sigma \text{ LER x occupation time (sole stand)}}{\Sigma \text{ occupation time (mixture) x } i}$$

where i is the number of crops compared

Practical Application of Sorghum/Millet Intercropping

With high levels of mechanization, sorghum/millet intercrops cannot be recommended to increase yields, because only yield reductions, but no yield increases of intercrops compared to sole sorghum were found, at least with yield levels of present millet hybrids. Since mechanization allows only relatively small temporal differences, it must be questioned that even with higher yielding millet hybrids (higher harvest index) yield increases could be obtained.

Under conditions, however, where selective harvest is possible, and where the growing season is longer than individual crops require, like with an 85-day millet in an 185 day growing season in the Guinea savanna, better use of the environment, resulting in yield increases, can presumably be made by intercrops.

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APPENDIX

Table A1. Climatic data, St. John and Garden City, 1980.

	St. John				Garden City			
	Min. Temperature	Max. Temperature	Avg. Temperature	Precip.	Min. Temperature	Max. Temperature	Avg. Temperature	Precip.
May	10.8	25.3	18.1	50.3	7.8	21.3	14.6	145.0
June	18.5	34.9	26.7	12.7	15.8	31.9	24.2	39.9
July	22.3	39.8	31.1	40.4	19.3	37.5	28.4	12.7
August	20.6	30.1	28.3	119.9	17.5	33.0	25.3	71.1
September	51.3	31.3	23.3	40.0	12.2	28.5	20.4	0.1
October	6.6	23.7	15.2	24.9	2.2	23.2	12.7	3.8

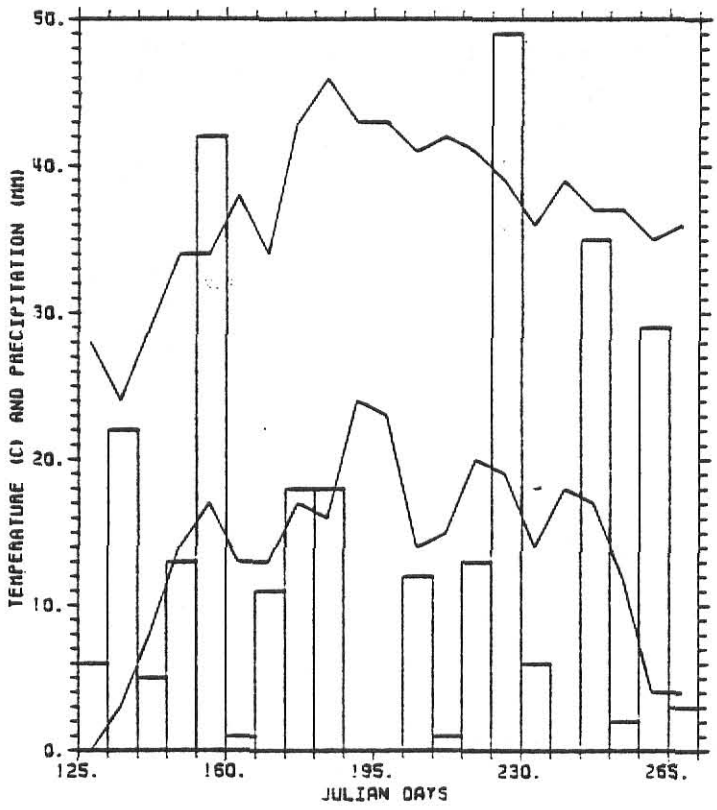

Figure 9. Manhattan precipitation (bar graph), minimum and maximum temperature.

Table A2. Sorghum dry matter accumulation (kg/.5 ha), Ashland irrigated.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand	1341.9	1481.3	1263.1	1362.1	188
alternate rows	1624.0	1661.7	1514.1	1600.0	
within-row mixt.	1034.6	1527.2	1270.8	1302.5	
hybrid average	1360.7	1556.8	1356.5		
sole stand	2767.4	2810.0	2333.8	2664.6	193
alternate rows	2248.5	2787.1	2928.1	2691.5	
within-row mixt.	2030.8	2690.3	2429.5	2355.6	
hybrid average	2358.0	2769.0	2584.7		
sole stand	3409.9	3113.5	4053.5	3536.1	199
alternate rows	2792.0	3336.6	3584.3	3237.6	
within-row mixt.	3678.9	2486.9	2349.1	2789.4	
hybrid average	3243.4	3023.7	3329.0		
sole stand	4522.6	5050.9	4245.4	4639.1	206
alternate rows	4012.5	4404.5	4081.4	4166.1	
within-row mixt.	3584.9	3715.6	4099.4	3819.5	
hybrid average	4081.4	4390.4	4132.7		
sole stand	4844.7	5772.6	5640.9	5454.7 a	213
alternate rows	3554.2	4313.2	6128.6	4811.7 ab	
within-row mixt.	4235.6	4770.3	4247.0	4417.7 b	
hybrid average	4213.9 b	5010.1 a	5311.4 a		
sole stands	5725.1	5761.2	5876.0	5787.4	220
alternate rows	4635.8	5800.5	5410.1	5235.0	
within-row mixt.	3945.2	6273.0	5482.3	5233.5	
hybrid average	4768.7	5958.0	5589.5		
sole stand	7854.3	8515.4	7915.0	8116.8	phys.mat.
alternate rows	6087.6	8018.4	9717.8	7941.4	
within-row mixt.	5842.1	9663.2	9099.4	8291.3	
hybrid average	6544.0 b	8647.7 a	8910.8 a		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A3. Sorghum nitrogen uptake (kg/.5 ha), Ashland irrigated.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day phys.mat.
sole stand	41.84	41.59	39.87	41.08 ab	188
alternate rows	48.01	49.83	43.13	46.99 a	
within-row mixt.	28.91	40.28	35.20	35.35 b	
hybrid average	40.56	43.88	39.78		
sole stand	65.91	76.64	62.61	68.91	193
alternate rows	59.16	72.68	70.11	68.06	
within-row mixt.	58.07	66.37	60.82	62.06	
hybrid average	61.92	72.40	64.69		
sole stand	79.79	69.18	84.28	77.57 a	199
alternate rows	58.20	68.02	61.07	62.44 ab	
within-row mixt.	64.15	41.46	41.02	48.09 b	
hybrid average	66.46	61.20	62.12		
sole stand	103.49	110.01	106.35	106.64 a	206
alternate rows	85.60	83.21	69.70	79.50 b	
within-row mixt.	68.83	74.78	69.28	71.16 b	
hybrid average	87.53	89.33	79.54		
sole stand	93.63	104.55	85.42	95.53 a	213
alternate rows	63.38	69.02	94.36	77.46 b	
within-row mixt.	66.77	76.63	60.72	68.04 b	
hybrid average	73.81	84.71	79.69		
sole stand	91.01	82.02	99.97	91.00	220
alternate rows	73.90	92.17	74.89	79.24	
within-row mixt.	55.06	91.79	85.92	77.59	
hybrid average	73.32	88.34	86.93		
sole stand	108.07	103.01	93.63	100.98 a	
alternate rows	78.50	86.94	91.47	85.63 b	
within-row mixt.	69.68	107.75	101.14	93.69 ab	
hybrid average	84.72	98.46	95.41		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A4. Sorghum phosphorus uptake (kg/.5 ha), Ashland irrigated.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand	6.759	6.510	6.325	6.531 a	188
alternate rows	6.659	6.903	6.241	6.601 a	
within-row mixt.	4.211	5.878	4.775	5.047 b	
hybrid average	6.028	6.430	5.872		
sole stand	10.779	10.260	8.814	10.071	193
alternate rows	8.345	9.723	10.513	9.634	
within-row mixt.	9.222	10.186	8.354	9.157	
hybrid average	9.626	10.044	9.278		
sole stand	13.235	11.098	14.385	12.876	199
alternate rows	9.566	11.588	12.861	11.338	
within-row mixt.	15.324	8.490	8.055	10.366	
hybrid average	12.394	10.565	11.767		
sole stand	17.411	18.668	15.879	17.450 a	206
alternate rows	12.777	13.569	13.774	13.373 b	
within-row mixt.	10.599	11.716	11.439	11.310 b	
hybrid average	13.868	14.651	13.499		
sole stand	17.817	19.194	17.497	18.272 a	213
alternate rows	11.677	13.938	19.211	15.369 b	
within-row mixt.	13.186	14.175	12.400	13.247 b	
hybrid average	14.155	15.935	16.267		
sole stand	17.814	17.064	20.231	18.370	220
alternate rows	13.763	19.049	16.855	16.329	
within-row mixt.	11.560	20.249	16.051	15.953	
hybrid average	14.379 b	18.763 a	17.713 a		
sole stand	23.195	22.294	20.244	21.794	phys.mat.
alternate rows	17.719	22.334	27.522	22.525	
within-row mixt.	15.069	24.914	21.689	20.670	
hybrid average	18.567 b	23.023 a	23.152 a		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A5. Sorghum potassium uptake (kg/.5 ha), Ashland irrigated.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand	65.37	80.17	64.55	70.03	188
alternate rows	72.89	75.37	76.32	74.86	
within-row mixt.	45.37	70.39	61.20	60.13	
hybrid average	62.65	75.31	67.92		
sole stand	98.74	88.25	91.85	93.05	193
alternate rows	72.57	92.61	104.54	91.48	
within-row mixt.	69.69	90.91	83.23	82.78	
hybrid average	83.56	90.56	93.33		
sole stand	119.06	97.35	147.00	121.33	199
alternate rows	89.89	110.51	141.01	113.80	
within-row mixt.	135.53	88.80	85.66	110.56	
hybrid average	112.33	99.80	124.55		
sole stand	123.04	148.79	106.35	129.34	206
alternate rows	98.74	130.47	138.76	122.66	
within-row mixt.	102.05	84.52	125.86	104.33	
hybrid average	108.48	121.25	126.72		
sole stand	128.09	163.62	184.84	159.33 a	213
alternate rows	88.67	115.38	153.79	122.73 b	
within-row mixt.	141.15	121.31	113.86	125.37 b	
hybrid average	121.49 b	135.08 ab	147.67 a		
sole stand	115.24	126.33	144.30	128.62	220
alternate rows	96.52	131.66	135.15	120.41	
within-row mixt.	88.27	133.87	125.47	115.87	
hybrid average	100.01 b	130.53 a	134.97 a		
sole stand	154.87	145.07	139.97	145.89 a	phys.mat.
alternate rows	116.93	117.35	159.61	131.29 ab	
within-row mixt.	99.71	127.34	119.79	116.03 b	
hybrid average	123.14	130.16	139.79		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A6. Millet dry matter accumulation (kg/.5 ha), Ashland irrigated.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand				1937.3	188
alternate rows	2122.7	2180.1	1822.5	2041.8	
within-row mixt.	2683.1	1763.5	1942.3	2079.5	
hybrid average	2363.1	1971.8	1882.4		
sole stand				2974.1 b	193
alternate rows	3464.6	2808.4	2731.8	3026.1 b	
within-row mixt.	4518.8	3339.9	3725.4	3847.8 a	
hybrid average	3916.4	3036.2	3299.6		
sole stand				3789.4	199
alternate rows	3474.4	3645.0	3581.3	3566.9	
within-row mixt.	3523.6	3605.6	3407.2	3511.1	
hybrid average	3495.5	3625.3	3694.2		
sole stand				4545.1	206
alternate rows	4870.4	4842.5	4516.1	4723.1	
within-row mixt.	5234.0	4361.9	4125.7	4513.8	
hybrid average	5026.2	4522.1	4320.9		
sole stand				6402.6	213
alternate rows	6430.4	6002.3	5864.5	6069.0	
within-row mixt.	6732.3	6273.0	6697.8	6567.7	
hybrid average	6602.9	6137.6	6281.2		
sole stand				5656.2	220
alternate rows	5999.6	6476.4	5172.8	5713.3	
within-row mixt.	8029.3	4488.2	6334.2	6797.0	
hybrid average	7014.4	5482.3	5753.5		
sole stand				6220.5 ab	phys.mat.
alternate rows	7126.0	7259.4	6259.8	6847.4 a	
within-row mixt.	6983.3	5577.4	5365.8	5975.5 b	
hybrid average	7054.6 a	6298.3 ab	5812.8 b		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A7. Millet nitrogen uptake (kg/.5 ha), Ashland irrigated.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day phys.mat.
sole stand				46.86	188
alternate rows	62.93	69.24	48.15	60.11	
within-row mixt.	80.55	67.12	59.71	68.09	
hybrid average	70.48	68.18	53.93		
sole stand				75.63 b	193
alternate rows	95.97	83.56	75.29	85.82 b	
within-row mixt.	121.56	106.08	109.88	112.24 a	
hybrid average	106.94	93.21	95.06		
sole stand				89.57	199
alternate rows	78.96	93.99	95.06	89.33	
within-row mixt.	90.17	88.60	88.56	89.01	
hybrid average	83.77	91.30	91.79		
sole stand				86.83	206
alternate rows	94.83	116.50	105.11	103.28	
within-row mixt.	121.16	99.40	101.19	105.99	
hybrid average	106.12	105.10	103.15		
sole stand				111.04	213
alternate rows	138.11	121.24	98.52	117.58	
within-row mixt.	132.32	108.25	111.65	117.41	
hybrid average	134.80 a	114.75 ab	105.09 b		
sole stand				88.50	220
alternate rows	--	103.16	90.61	93.75	
within-row mixt.	143.06	--	--	143.06	
hybrid average	143.06	103.06	90.61		
sole stand				85.05 b	
alternate rows	111.54	108.71	91.22	103.38 a	
within-row mixt.	101.22	86.18	85.89	91.10 b	
hybrid average	106.38 a	95.84 ab	88.55 b		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A8. Millet phosphorus uptake (kg/.5 ha), Ashland irrigated.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand				8.033	188
alternate rows	8.518	9.472	8.540	8.843	
within-row mixt.	11.304	6.447	7.878	8.292	
hybrid average	9.712	7.959	8.209		
sold stand				12.948	193
alternate rows	14.023	13.214	12.304	13.260	
within-row mixt.	19.013	14.007	12.888	15.061	
hybrid average	16.162	13.554	12.638		
sole stand				14.528	199
alternate rows	12.340	13.943	18.669	14.984	
within-row mixt.	13.283	12.645	11.641	12.454	
hybrid average	12.744	13.294	15.155		
sole stand				20.573	206
alternate rows	17.317	17.191	19.312	18.090	
within-row mixt.	21.842	14.219	13.150	15.909	
hybrid average	19.256	15.210	16.231		
sole stand				23.338	213
alternate rows	23.530	19.629	21.448	21.354	
within-row mixt.	26.518	19.375	17.568	21.153	
hybrid average	25.238 a	19.502 b	19.508 b		
sole stand				25.958	220
alternate rows	--	21.140	17.211	18.194	
within-row mixt.	28.401	--	--	28.401	
hybrid average	28.401	21.140	17.211		
sole stand				27.264 a	phys.mat.
alternate rows	25.167	23.900	22.960	24.019 a	
within-row mixt.	23.169	19.823	14.322	19.104 b	
hybrid average	24.168 a	21.570 ab	18.641 b		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A9. Millet potassium uptake (kg/.5 ha), Ashland irrigated.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day phys.mat.
sole stand				117.76	188
alternate rows	132.91	136.27	113.99	127.72	
within-row mixt.	170.13	105.23	122.10	129.07	
hybrid average	148.86	120.75	118.05		
sole stand				134.76	193
alternate rows	158.49	124.00	113.91	133.79	
within-row mixt.	201.43	150.86	142.29	162.60	
hybrid average	176.89 a	135.51 b	130.13 b		
sole stand				149.15	199
alternate rows	150.92	148.73	165.08	154.91	
within-row mixt.	151.61	153.83	140.39	148.33	
hybrid average	151.21	151.28	152.73		
sole stand				174.62	206
alternate rows	191.64	177.44	162.62	177.05	
within-row mixt.	165.69	172.29	163.62	167.30	
hybrid average	180.52	174.00	162.94		
sole stand				220.56	213
alternate rows	220.60	207.62	200.57	208.60	
within-row mixt.	226.44	247.97	260.98	245.13	
hybrid average	223.94	227.79	230.78		
sole stand				158.85	220
alternate rows	--	184.95	160.27	166.44	
within-row mixt.	236.39	--	--	236.39	
hybrid average	236.39	184.95	160.27		
sole stand				136.49 b	
alternate rows	171.17	185.96	148.54	166.97 a	
within-row mixt.	169.17	153.35	137.99	153.50 ab	
hybrid average	170.17 a	167.33 a	143.26 b		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A10. Dry matter, nitrogen, phosphorus and potassium accumulation by vegetative sorghum parts and sorghum heads (kg/.5 ha), Ashland irrigated.

		vegetative parts			heads			Julian day
		ACCO 1014	Pioneer 8324	DeKalb F67	ACCO 1014	Pioneer 8324	DeKalb F67	
dry matter	sole stand	2229.3	2977.4	4417.7	3495.7	2783.8	1458.3	220
	alternate rows	2062.0	2987.8	3984.6	2573.8	2568.9	1425.5	
	within-row mixtures	2021.0	3148.0	3850.1	1924.2	3125.0	1632.2	
	sole stand	3482.1	3989.5	4240.5	4372.3	4525.9	3674.5	p.m.
	alternate rows	2698.5	4320.9	5054.1	3389.1	4320.9	4663.7	
	within-row mixtures	2642.7	4413.8	4604.7	3302.7	5224.7	4494.8	
nitrogen	sole stand	31.70	37.08	77.80	59.31	44.95	22.17	220
	alternate rows	28.44	44.35	53.25	45.45	43.67	21.65	
	within-row mixtures	26.97	41.88	59.81	28.09	49.91	26.12	
	sole stand	34.04	36.92	41.26	74.02	66.09	52.37	p.m.
	alternate rows	23.29	32.34	31.52	55.21	54.61	59.95	
	within-row mixtures	23.81	39.10	58.65	46.89	68.49	58.65	
phosphorus	sole stand	5.021	7.670	15.700	12.792	9.391	4.532	220
	alternate rows	4.960	9.626	12.546	8.803	8.606	4.309	
	within-row mixtures	5.152	9.491	11.480	6.408	10.758	4.570	
	sole stand	5.708	7.646	8.580	17.490	14.648	11.663	p.m.
	alternate rows	5.239	7.414	12.394	12.480	14.920	15.128	
	within-row mixtures	4.936	10.600	8.513	10.260	14.869	13.175	
potassium	sole stand	69.66	90.72	125.49	45.59	35.61	18.81	220
	alternate rows	65.73	102.13	119.23	30.78	26.97	15.92	
	within-row mixtures	69.94	97.23	109.80	18.33	36.64	15.67	
	sole stand	123.67	123.56	120.57	31.20	21.51	19.40	p.m.
	alternate rows	93.98	94.02	137.93	22.94	23.33	21.68	
	within-row mixtures	90.61	108.87	99.68	16.11	21.15	20.11	

Table A11. Dry matter, nitrogen, phosphorus and potassium accumulation by vegetative millet parts and millet heads (kg/.5 ha), Ashland irrigated.

		vegetative parts				heads				
		ACCO 1014	Pioneer 8324	DeKalb F67	sole millet	ACCO 1014	Pioneer 8324	DeKalb F67	sole millet	
dry matter	sole stand				3825.5				2283.5	220
	alternate rows	3613.3	3713.9	2836.8		2322.8	2607.2	2350.7		
	within-row mixt.	3738.5	2675.5	3802.5		3657.0	1994.8	2325.0		
	sole stand				3546.6				2673.9	p.m.
	alternate rows	3996.1	4435.7	3594.2		3129.9	2823.7	2665.7		
	within-row mixt.	3822.2	3257.9	3502.3		3161.1	2319.6	1863.5		
nitrogen	sole stand				53.83				39.96	220
	alternate rows	57.91	59.31	47.86		--	51.67	43.02		
	within-row mixt.	59.32	46.05	67.37		72.04	--	--		
	sole stand				40.74				44.31	p.m.
	alternate rows	55.61	56.97	43.10		55.92	51.75	48.12		
	within-row mixt.	46.40	42.19	50.61		54.83	43.99	35.27		
phosphorus	sole stand				18.723				10.731	220
	alternate rows	13.234	10.739	8.989		--	10.559	8.274		
	within-row mixt.	12.167	7.429	10.487		14.701	--	--		
	sole stand				17.686				9.578	p.m.
	alternate rows	14.191	13.075	14.009		10.976	10.825	8.951		
	within-row mixt.	11.612	10.963	7.696		11.557	8.860	6.626		
potassium	sole stand				149.03				28.77	220
	alternate rows	156.11	162.30	135.65		--	22.94	24.87		
	within-row mixt.	167.92	117.51	167.33		38.76	--	--		
	sole stand				119.76				16.73	p.m.
	alternate rows	152.69	167.80	136.57		18.48	18.16	11.97		
	within-row mixt.	146.55	139.27	126.87		22.63	14.08	11.11		

Julian day

Table A12. Sorghum dry matter accumulation (kg/.5 ha), Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand	1651.9	1312.3	1223.8	1396.0	188
alternate rows	1482.9	1243.4	1799.5	1508.6	
within-row mixt.	1031.8	1514.1	1186.0	1244.0	
hybrid average	1388.9	1356.6	1403.1		
sole stand	2150.6	2317.9	1710.9	2059.8 b	193
alternate rows	3062.7	2570.5	2600.1	2744.4 a	
within-row mixt.	1504.8	2075.1	1509.2	1713.8 b	
hybrid average	2306.1	2321.2	1940.1		
sole stand	3080.4	3269.4	2459.0	2915.6	199
alternate rows	2928.1	2591.9	2406.5	2642.2	
within-row mixt.	2693.6	2749.3	2234.3	2559.1	
hybrid average	2880.0	2870.2	2366.6		
sole stand	3987.3	3602.4	3646.7	3735.6 a	206
alternate rows	3336.6	3454.7	2963.7	3277.9 ab	
within-row mixt.	2979.0	2900.3	2681.6	2853.6 b	
hybrid average	3424.5	3332.7	3152.2		
sole stand	4899.9	4365.2	4386.5	4550.5 a	213
alternate rows	4486.5	3512.1	3170.9	3723.2 ab	
within-row mixt.	3116.8	3551.5	2628.0	3098.8 b	
hybrid average	4167.8	3809.6	3395.1		
sole stand	5851.4	4831.0	4836.0	5172.8 a	220
alternate rows	3804.1	3566.3	4891.7	4087.4 b	
within-row mixt.	3092.7	4629.3	3672.4	3881.2 b	
hybrid average	4354.6	4342.2	4538.9		
sole stand	4722.8	6287.7	7127.6	6046.0	phys.mat.
alternate rows	4132.2	6069.5	6922.6	5635.8	
within-row mixt.	3193.9	5544.6	6356.6	5031.7	
hybrid average	4016.3 b	5946.9 a	6802.3 a		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A13. Sorghum nitrogen uptake (kg/.5 ha), Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand	47.07	39.52	37.48	41.36	188
alternate rows	40.33	35.52	54.70	43.51	
within-row mixt.	29.95	40.28	39.89	36.71	
hybrid average	39.12	38.44	44.03		
sole stand	56.96	63.30	45.90	55.39 a	193
alternate rows	65.94	52.18	57.02	58.38 a	
within-row mixt.	31.90	42.76	34.59	36.83 b	
hybrid average	53.39	52.75	45.83		
sole stand	63.84	66.20	49.91	59.98 a	199
alternate rows	50.81	46.65	42.01	46.49 b	
within-row mixt.	53.30	54.68	38.06	48.68 b	
hybrid average	55.98 a	55.84 a	43.33 b		
sole stand	71.17	74.54	82.58	76.74 a	206
alternate rows	52.93	73.13	60.18	62.25 b	
within-row mixt.	49.84	50.21	43.56	47.87 c	
hybrid average	57.48	66.68	64.15		
sole stand	91.17	78.00	80.40	83.19 a	213
alternate rows	69.74	54.18	51.07	58.33 b	
within-row mixt.	51.41	58.41	38.48	49.43 b	
hybrid average	70.77	63.53	56.65		
sole stand	69.45	90.71	88.63	82.93	phys.mat.
alternate rows	59.97	77.59	90.55	75.72	
within-row mixt.	42.61	79.34	77.24	66.40	
hybrid average	57.34 b	83.54 a	85.47 a		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A14. Sorghum phosphorus uptake (kg/.5 ha), Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand	6.969	6.049	4.777	5.932 a	188
alternate rows	5.618	4.436	7.415	5.823 a	
within-row mixt.	3.462	5.346	4.490	4.433 b	
hybrid average	5.350	5.277	5.561		
sole stand	6.006	5.679	4.713	5.466 b	193
alternate rows	9.226	6.730	6.234	7.397 a	
within-row mixt.	3.896	5.290	4.602	4.660 b	
hybrid average	6.602	5.900	5.182		
sole stand	7.018	5.916	5.052	5.996	199
alternate rows	7.902	5.953	5.079	6.612	
within-row mixt.	6.493	9.790	4.319	6.867	
hybrid average	7.138 a	7.220 a	4.817 b		
sole stand	8.525	6.314	8.079	7.684	206
alternate rows	7.163	8.536	5.772	7.283	
within-row mixt.	5.197	6.068	5.285	5.517	
hybrid average	6.982	7.129	6.548		
sole stand	10.301	8.512	7.545	8.816	213
alternate rows	11.428	6.817	5.653	7.966	
within-row mixt.	8.046	6.928	4.174	6.383	
hybrid average	9.955 a	7.419 b	5.791 b		
sole stand	8.194	10.055	10.642	9.630	phys.mat.
alternate rows	8.838	12.025	13.657	11.403	
within-row mixt.	13.810	11.794	10.832	12.145	
hybrid average	10.281	11.145	11.710		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A15. Sorghum potassium uptake (kg/.5 ha), Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day phys.mat.
sole stand	79.96	68.50	57.69	68.71	188
alternate rows	64.03	60.59	94.13	72.92	
within-row mixt.	46.35	66.99	56.09	56.48	
hybrid average	63.45	65.36	69.30		
sole stand	70.74	75.73	58.67	68.38 b	193
alternate rows	97.35	77.61	87.56	87.51 a	
within-row mixt.	42.33	60.84	56.50	54.22 b	
hybrid average	72.67	71.39	67.57		
sole stand	90.47	96.30	77.14	87.97	199
alternate rows	91.40	79.64	83.78	84.94	
within-row mixt.	80.55	102.89	69.49	84.31	
hybrid average	87.48	92.94	76.80		
sole stand	102.02	93.67	102.34	99.65	206
alternate rows	101.45	83.71	86.83	91.01	
within-row mixt.	75.98	80.65	80.00	78.88	
hybrid average	93.98	85.78	90.99		
sole stand	121.32	99.41	114.44	111.72 a	213
alternate rows	130.27	89.17	92.95	104.13 a	
within-row mixt.	67.68	81.74	67.81	72.41 b	
hybrid average	106.42	90.11	91.74		
sole stand	71.80	91.94	103.37	89.04	
alternate rows	66.88	95.38	93.96	83.42	
within-row mixt.	46.83	82.02	87.93	72.26	
hybrid average	61.84 b	88.66 a	95.09 a		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A16. Millet dry matter accumulation (kg/.5 ha), Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand				1507.6	188
alternate rows	2064.7	2124.3	2042.3	2078.3	
within-row mixt.	2050.5	2616.5	2006.2	2224.4	
hybrid average	2056.6	2370.4	2024.3		
sole stand				2657.5 b	193
alternate rows	3333.3	3067.6	3115.3	3193.0 b	
within-row mixt.	4020.7	3646.1	4114.2	3952.5 a	
hybrid average	3677.0	3414.7	3614.7		
sole stand				3732.0	199
alternate rows	3672.9	3817.3	3554.8	3681.6	
within-row mixt.	4263.5	3919.0	3397.3	3859.9	
hybrid average	3968.2	3868.1	3476.0		
sole stand				4150.3	206
alternate rows	4817.9	4573.5	5045.9	4834.2	
within-row mixt.	5141.1	5984.3	3376.0	4603.7	
hybrid average	4979.5	5137.8	4211.0		
sole stand				4837.6	213
alternate rows	4693.2	4717.8	5973.3	5051.3	
within-row mixt.	6225.4	6061.4	5433.1	5906.6	
hybrid average	5459.3	5389.6	5664.6		
sole stand				5046.0	220
alternate rows	6168.0	4552.2	5421.6	5380.6	
within-row mixt.	7506.6	4521.0	5319.9	5897.2	
hybrid average	6837.3 a	4538.8 b	5370.7 b		
sole stand				5835.0	phys.mat.
alternate rows	5918.6	4732.6	3954.9	4856.3	
within-row mixt.	7572.2	4813.0	4535.8	5253.9	
hybrid average	6580.1 a	4772.8 b	4288.5 b		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A17. Millet nitrogen uptake (kg/.5 ha), Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand				39.89	188
alternate rows	57.68	62.24	62.36	61.04	
within-row mixt.	63.62	71.25	64.74	66.54	
hybrid average	61.07	66.75	63.55		
sole stand				71.82 b	193
alternate rows	82.26	93.27	89.99	87.56 b	
within-row mixt.	106.44	102.72	113.18	107.87 a	
hybrid average	94.35	98.94	101.58		
sole stand				70.95	199
alternate rows	74.14	85.74	83.56	81.15	
within-row mixt.	98.06	77.99	79.64	85.22	
hybrid average	86.10	81.82	81.60		
sole stand				77.41	206
alternate rows	105.32	97.18	116.14	107.04	
within-row mixt.	117.54	130.03	73.01	102.22	
hybrid average	111.43	110.32	94.58		
sole stand				83.02	213
alternate rows	87.50	89.11	114.28	95.39	
within-row mixt.	125.12	111.48	99.99	112.19	
hybrid average	106.31	100.29	106.12		
sole stand				92.08	phys.mat.
alternate rows	100.90	73.68	62.20	78.40	
within-row mixt.	109.48	76.55	74.14	82.16	
hybrid average	104.33 a	75.12 b	69.02 b		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A18. Millet phosphorus uptake (kg/.5 ha), Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand				5.724	188
alternate rows	7.990	8.896	9.384	8.823	
within-row mixt.	8.782	10.924	7.900	9.202	
hybrid average	8.443	9.910	8.642		
sole stand				8.252 b	193
alternate rows	8.461	8.587	7.419	8.069 b	
within-row mixt.	10.538	10.595	13.122	11.490 a	
hybrid average	9.499	9.792	10.266		
sole stand				9.479	199
alternate rows	9.707	10.773	9.814	10.093	
within-row mixt.	10.138	9.152	7.920	9.070	
hybrid average	9.922	9.962	8.867		
sole stand				7.887	206
alternate rows	10.894	10.476	11.390	10.960	
within-row mixt.	10.376	12.871	6.896	9.483	
hybrid average	10.635	11.434	9.143		
sole stand				8.396	213
alternate rows	9.406	8.937	11.144	9.710	
within-row mixt.	12.438	9.914	10.104	10.819	
hybrid average	10.922	9.425	10.550		
sole stand				12.525	phys. mat.
alternate rows	17.041	10.033	7.421	11.352	
within-row mixt.	16.548	9.131	9.834	10.896	
hybrid average	16.844 a	9.582 b	8.800 b		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A19. Millet potassium uptake (kg/.5 ka), Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	Julian day
sole stand				100.0	188
alternate rows	134.5	135.3	133.7	134.5	
within-row mixt.	137.1	168.9	122.9	142.9	
hybrid average	136.0	152.1	128.3		
sole stand				110.9	
alternate rows	156.4	134.9	141.9	146.3	193
within-row mixt.	169.5	149.2	184.6	169.5	
hybrid average	162.9	143.5	163.3		
sole stand				160.5	
alternate rows	152.8	162.3	154.3	156.5	199
within-row mixt.	190.5	161.1	141.6	164.4	
hybrid average	171.6	161.7	147.9		
sole stand				152.1	
alternate rows	184.2	180.1	169.2	177.6	206
within-row mixt.	169.0	236.6	120.4	163.1	
hybrid average	176.6 ab	202.7 a	144.8 b		
sole stand				170.5	
alternate rows	171.5	187.1	236.6	194.9	213
within-row mixt.	221.1	206.9	200.6	209.9	
hybrid average	196.8	197.0	216.0		
sole stand				146.8	phys.mat.
alternate rows	122.3	118.1	93.3	111.9	
within-row mixt.	143.1	116.3	101.7	115.8	
hybrid average	130.6	117.2	98.1		

Average values with the same or no letter within one Julian day are not significantly (5%) different.

Table A20. Dry matter, nitrogen, phosphorus and potassium accumulation by vegetative sorghum parts and sorghum heads (kg/.5 ha), Ashland dryland.

		vegetative parts			heads			Julian day
		ACCO 1014	Pioneer 8324	DeKalb F67	ACCO 1014	Pioneer 8324	DeKalb F67	
dry matter	sole stand	3120.1	3505.6	4291.3	2731.3	1325.5	544.6	220
	alternate rows	1983.3	3174.2	4340.6	1820.9	392.1	551.2	
	within-row mixtures	1758.5	3476.1	2757.5	1443.6	1153.2	365.3	
	sole stand	2496.7	3753.3	3928.9	2226.1	2534.4	3198.8	p.m.
	alternate rows	1986.5	4347.1	4519.4	2145.7	1061.4	2403.2	
	within-row mixtures	1612.5	3576.1	3912.4	1581.4	1968.5	2444.2	
nitrogen	sole stand	37.93	55.38	67.71				220
	alternate rows	18.99	43.77	58.97				
	within-row mixtures	19.02	46.93	34.30				
	sole stand	27.22	45.09	35.17	42.23	45.62	53.45	p.m.
	alternate rows	18.66	46.84	52.42	41.31	18.71	38.12	
	within-row mixtures	14.93	43.52	40.10	27.68	35.82	37.14	
phosphorus	sole stand	3.520	4.509	7.014				220
	alternate rows	2.294	4.612	5.965				
	within-row mixtures	2.365	4.843	4.086				
	sole stand	2.834	4.189	3.951	5.360	5.866	6.691	p.m.
	alternate rows	2.227	6.905	7.028	6.611	3.073	6.629	
	within-row mixtures	9.717	6.533	5.233	4.039	5.262	5.600	
potassium	sole stand	87.64	71.98	94.46				220
	alternate rows	62.75	72.44	97.65				
	within-row mixtures	51.91	76.86	66.69				
	sole stand	61.32	82.64	91.31	10.48	9.30	12.06	p.m.
	alternate rows	52.62	88.73	82.60	14.27	4.12	11.37	
	within-row mixtures	38.01	73.95	72.66	8.81	8.07	10.27	

Table A21. Dry matter, nitrogen, phosphorus and potassium accumulation by vegetative millet parts and millet heads (kg/.5 ha), Ashland dryland.

		vegetative parts				heads				Julian day
		ACCO 1014	Pioneer 8324	DeKalb F67	sole millet	ACCO 1014	Pioneer 8324	DeKalb F67	sole millet	
dry matter	sole stand				3538.4				1507.5	220 p.m.
	alternate rows	4363.5	3331.7	3978.0		1804.5	1220.5	1443.6		
	within-row mixt.	4903.2	3501.8	3812.3		2603.3	1127.0	1507.5		
	sole stand				4083.0				1752.0	
	alternate rows	3716.1	3133.2	2327.8		2119.4	1599.4	1356.1		
	within-row mixt.	4714.6	3239.8	3067.6		2714.3	1573.2	1468.2		
nitrogen	sole stand				52.27					220 p.m.
	alternate rows	73.23	54.79	69.88						
	within-row mixt.	77.98	54.60	67.82						
	sole stand				58.98				33.11	
	alternate rows	57.23	42.32	32.21		41.54	30.36	27.36		
	within-row mixt.	52.78	44.18	45.44		53.83	32.37	28.70		
phosphorus	sole stand				4.563					220 p.m.
	alternate rows	5.398	4.367	5.426						
	within-row mixt.	5.649	4.205	4.842						
	sole stand				7.275				5.250	
	alternate rows	9.662	4.768	3.250		6.946	5.264	3.938		
	within-row mixt.	7.598	4.726	5.967		8.517	4.405	3.867		
potassium	sole stand				108.82					220 p.m.
	alternate rows	162.37	104.74	127.91						
	within-row mixt.	167.96	109.66	124.91						
	sole stand				135.77				11.04	
	alternate rows	109.25	107.49	77.98		12.34	10.64	5.61		
	within-row mixt.	126.87	107.93	94.44		15.27	8.37	7.23		

Table A22. Millet grain yields (kg/.5 ha) and yield components, Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	
sole stand				732.1	grain yield/.5 ha (kg)
alternate rows	923.0	700.5	839.4	820.9	
within-row mixt.	1307.0	682.9	684.3	891.4	
hybrid average	1115.0	691.7	761.8		
sole stand				.500	(LER)
alternate rows	.601	.469	.617	.562	
within-row mixt.	.972	.492	.482	.649	
hybrid average	.787	.481	.550		
sole stand				82613	head no. (.5 ha)
alternate rows	122708	109253	101719	111227	
within-row mixt.	116519	118134	111944	115533	
hybrid average	119614	113693	106832		
sole stand				9.21	grain yield/ head(g)
alternate rows	7.55	6.50	10.15	8.06	
within-row mixt.	10.94	5.75	5.91	7.54	
hybrid average	9.24	6.13	8.03		
sole stand				719.8	seeds/ head
alternate rows	614.1	526.8	750.4	630.5	
within-row mixt.	819.5	445.4	451.0	572.0	
hybrid average	716.8	486.1	600.7		
sole stand				11.05	1000 seed weight(g)
alternate rows	10.68	10.65	11.65	10.99	
within-row mixt.	11.63	11.30	11.35	11.43	
hybrid average	11.15	10.98	11.50		

Table A23. Total grain yields (sorghum + millet) in kg/ha and on an LER basis, Ashland dryland.

	ACCO 1014	Pioneer 8324	DeKalb F67	crop.syst. average	
sole stand	3243.2	3708.9	4120.8	3690.9 a	grain yield (kg/ha)
alternate rows	1887.9	1357.9	2266.9	1837.5 b	
within-row mixt.	2167.4	1570.9	1734.8	1824.4 b	
hybrid average	2432.8	2212.5	2707.5		
sole stand	1.000	1.000	1.000	1.000	grain yield (LER)
alternate rows	0.898	0.672	0.969	0.918	
within-row mixt.	1.242	0.773	0.738	0.846	

Table A24. Sorghum and millet grain yields and yield components, Garden City.

	sorghum			millet				
	ACCO 1014	Pioneer 8324	DeKalb F67	ACCO 1014	Pioneer 8324	DeKalb F67	sole millet	
sole stand	888.1	1393.8	391.1				273.9	grain yield/.5 ha (kg)
alternate rows	1163.0	537.1	--	273.6	198.4	226.7		
within-row mixtures	1012.4	833.8	115.6	219.5	176.7	159.5		
sole stand	0.50	0.50	0.50				0.50	(LER)
alternate rows	0.66	0.26	--	0.51	0.62	0.34		
within-row mixtures	0.67	0.28	0.25	0.30	0.41	0.30		
sole stand	25,116	31,313	24,790				44,034	head no. (.5 ha)
alternate rows	33,923	39,794	--	35,227	55,450	52,624		
within-row mixtures	32,618	21,745	24,790	28,704	25,116	44,360		
sole stand	35.16	43.22	14.08				4.93	grain yield/ head
alternate rows	34.36	14.78	--	7.39	4.18	4.46		
within-row mixtures	30.75	38.20	5.86	8.72	10.54	3.60		
sole stand	1370	1609	623				362	seeds/ head
alternate rows	1476	577	--	541	288	330		
within-row mixtures	1371	1373	290	594	729	264		
sole stand	23.00	23.06	19.19				11.98	1000 seed weight(g)
alternate rows	20.13	22.31	16.33	11.95	12.49	11.83		
within-row mixtures	19.17	24.33	17.17	12.80	12.55	11.75		

Table A25. Sorghum and millet grain yields and yield components, St. John.

	sorghum			millet				
	ACCO 1014	Pioneer 8324	DeKalb F67	ACCO 1014	Pioneer 8324	DeKalb F67	sole millet	
sole stand	608.9	931.2	1212.0				877.8	grain yield/.5 ha (kg)
alternate rows	356.0	602.3	710.9	944.8	647.7	688.5		
within-row mixtures	336.0	868.2	926.2	734.0	903.6	806.6		
sole stand	0.50	0.50	0.50				0.50	(LER)
alternate rows	0.30	0.32	0.33	0.55	0.38	0.37		
within-row mixtures	0.29	0.48	0.37	0.42	0.47	0.49		
sole stand	61,648	42,077	40,122				236,806	head no. (.5 ha)
alternate rows	54,798	32,618	40,446	221,150	154,283	161,785		
within-row mixtures	59,691	41,099	37,184	172,875	207,450	195,381		
sole stand	10.74	22.33	30.31				3.78	grain yield/ head
alternate rows	6.09	18.29	16.90	4.23	5.03	3.94		
within-row mixtures	6.22	20.73	24.93	4.26	4.03	4.19		
sole stand	376	773	954				322	seeds/ head
alternate rows	230	708	647	372	402	320		
within-row mixtures	259	821	990	338	305	343		
sole stand	25.6	25.3	27.8				10.28	1000 seed weight(g)
alternate rows	22.9	22.4	22.0	9.98	10.80	10.63		
within-row mixtures	23.8	22.4	22.1	11.10	11.58	10.75		

Table A26. Analysis of variance for components, Julian day 188, irrigated.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	172 014	78.72	1.494	492.78
Cropping system	2	299 625	401.62*	8.607*	654.80
Sorghum x cropping system	4	35 711	31.79	0.667	121.01
Replications	3	313 470*	238.32	5.351*	831.57*
Error	22	100 863	87.86	1.601	215.13

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	619 803	684.00	9.166	2 705.90
Cropping system	1	65 459	470.40	0.256	193.80
Sorghum x cropping system	2	492 617	197.10	16.909	2 360.50
Replications	3	258 787	262.80	3.681	965.60
Error	17	389 558	733.10	7.915	1 711.80

Table A27. Analysis of variance for components, Julian day 193, irrigated.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	545 619	399.71	3.200	457.73
Cropping system	2	167 171	48.41	0.620	217.95
Sorghum x cropping system	4	400 377	81.26	5.949	578.28
Replications	3	554 586	443.48*	9.531	661.62
Error	21	279 482	(19)+126.56	(19)+3.642	(19)+469.69

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	11 555 086	439.02	24.510	4 933.50*
Cropping system	1	3 536 072*	3 596.21*	19.680	5 024.50
Sorghum x cropping system	2	169 821	102.75	8.231	99.20
Replications	3	1 100 899	805.73	16.693	1 912.70
Error	15	512 871	416.14	11.220	1 224.40

**Significant at 1% level *Significant at 5% level +Degrees of freedom in parentheses

Table A28. Analysis of variance for components, Julian day 199, irrigated.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	317 704	146.97	15.460	1 789.10
Cropping system	2	1 089 207	2 073.30*	14.328	738.70
Sorghum x cropping system	4	1 438 851	380.55	33.354	2 962.62
Replications	3	396 469	92.71	4.329	678.03
Error	21	1 226 887	415.12	23.528	2 274.63

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	24 130	53.40	10.136	10.5
Cropping system	1	100 305	9.22	29.725	125.9
Sorghum x cropping system	2	302 581	276.61	34.919	580.4
Replications	3	1 559 505	1 208.49*	14.788	1 483.6
Error	17	499 252	319.62	10.196	1 306.9

Table A29. Analysis of variance for components, Julian day 206, irrigated.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	380 104	136.35	4.094	925.62
Cropping system	2	1 960 950	4 000.65**	105.179**	1 703.54
Sorghum x cropping system	4	287 528	125.57	2.432	1 663.42*
Replications	3	500 987	315.15	3.337	610.79
Error	22	807 278	522.79	10.338	553.16

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	1 365 654	129.59	33.733	949.1
Cropping system	1	106 216	20.90	10.859	353.1
Sorghum x cropping system	2	733 474	1 101.34	65.763*	132.1
Replications	3	1 547 374	640.39	21.899	3 380.4
Error	14	958 491	634.72	15.903	1 491.4

**Significant at 1% level *Significant at 5% level

Table A30. Analysis of variance for components, Julian day 213, irrigated.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	3 151 998*	185.80	11.056	2 558.86*
Cropping system	2	2 982 457*	1 936.65*	68.764**	4 232.15**
Sorghum x cropping system	4	1 939 773*	630.44	21.525	2 504.61**
Replications	3	541 535	186.24	7.012	953.53
Error	20	638 512	348.19	8.851	447.04

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	567 597	2 094.58*	84.530*	126.1
Cropping system	1	909 614	88.69	2.697	7 384.6
Sorghum x cropping system	2	278 154	427.74	16.623	1 286.7
Replications	3	4 380 843	2 108.13**	57.705*	8 374.2*
Error	17	1 513 639	345.38	17.662	1 824.5

Table A31. Analysis of variance for components, Julian day 220, irrigated.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	3 558 665	724.64	55.011*	4 072.97*
Cropping system	2	1 369 545	661.11	20.673	540.54
Sorghum x cropping system	4	1 378 818	669.85	24.759	341.28
Replications	3	5 255 626*	1 218.53*	45.649	2 762.43
Error	23	1 409 971	261.19	11.206	955.42

Source of variation	d.f.	MILLET mean squares
		dry matter
Sorghum	2	5 109 363
Cropping system	1	1 224 348
Sorghum x cropping system	2	453 742
Replications	15	2 488 983

**Significant at 1% level *Significant at 5% level

Table A32. Analysis of variance for components, physiological maturity, irrigated.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	19 117 006**	680.32	80.374**	846.17
Cropping system	2	176 491	740.95*	12.256	2 249.00**
Sorghum x cropping system	4	5 543 189**	738.13*	63.605**	1 309.53*
Replications	3	4 913 133*	692.00*	45.068*	976.54*
Error	21	1 052 519	209.36	12.197	304.53

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	3 084 277*	636.02*	62.147*	1 790.7*
Cropping system	1	4 787 905*	952.81*	143.539**	1 177.5
Sorghum x cropping system	2	1 146 673	154.95	22.439	392.2
Replications	3	276 149	87.60	16.011	173.7
Error	17	585 949	115.25	12.160	429.6

**Significant at 1% level *Significant at 5% level

Table A33. Analysis of variance for components over all days, irrigated.

Source of variation	d.f.	SORGHUM mean squares dry matter	nitrogen	phosphorus	potassium
Replications	3	340 426	148.51	5.494	473.1
Day	6	154 216 270**	10 303.50**	843.511**	18 743.0**
Error I (Rep. x day)	18	2 032 727**	510.83*	19.144*	1 156.0
Sorghum	2	11 396 742**	966.74*	45.111*	6 079.1**
Cropping system	2	4 245 550**	6 208.39**	141.760**	7 056.3**
Sorghum x cropping system	4	2 780 340**	328.33	48.172**	2 302.0*
Day x cropping system	12	642 478	614.22	14.251	592.4
Day x sorghum	12	2 637 211**	225.90	20.063*	764.9
Day x sorghum x crop.syst.	24	1 403 688*	387.71	17.668*	1 183.0
Error II	148	(150)+795 289	283.27	10.250	749.4

Source of variation	d.f.	MILLET mean squares dry matter	d.f.	nitrogen	phosphorus	potassium
Replications	3	1 251 312	3	962.30	10.276	1 122.2
Day	6	70 133 183**	5	7 599.96**	624.684**	25 272.7**
Error I (Rep. x day)	18	1 829 740**	15	978.35**	26.460	2 969.0**
Sorghum	2	8 489 205**	2	2 287.87**	124.468**	5 031.8*
Cropping system	1	504 724	1	438.02	54.438*	1 878.5
Sorghum x cropping system	2	1 879 620	2	973.72	126.127**	601.5
Day x cropping system	6	1 767 474	5	955.08	29.586	2 473.9
Day x sorghum	12	808 124	11	375.49	17.769	1 083.8
Day x sorghum x crop.syst.	12	315 674	10	276.07	7.704	839.6
Error II	103	843 190	99	453.02	13.427	1 387.2

**Significant at 1% level *Significant at 5% level +Degrees of freedom in parentehses

Table A34. Analysis of variance for separated plant parts, Julian day 220, irrigated.

Source of variance	d.f.	SORGHUM VEG. PARTS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	11 830 113**	3 738.40**	202.095**	7 423.18**
Cropping system	2	236 690	200.23	1.887	26.75
Sorghum x cropping system	4	155 498	237.96	10.427	144.69
Replications	3	2 282 457*	476.61*	13.946	1 868.38
Error	23	646 764	100.57	5.446	755.10

Source of variation	d.f.	SORGHUM HEADS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	6 227 311**	1 932.71**	99.713**	970.54**
Cropping system	2	554 859	174.87	11.076*	347.74**
Sorghum x cropping system	4	1 151 732*	435.46**	17.682**	260.93**
Replications	3	1 121 033*	333.75*	12.319*	193.11**
Error	24	274 707	79.95	2.821	32.67

Source of variation	d.f.	MILLET VEG. PARTS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	711 756	122.46	34.671	1 329
Cropping system	1	5 508	26.63	1.575	1
Sorghum x cropping system	2	1 113 313	317.23	6.725	1 547
Replications	3	1 248 389	353.20	18.792	1 873
Error	13	922 946	346.59	11.751	2 191

Source of variation	d.f.	MILLET HEADS mean squares
		dry matter
Sorghum	2	871 926
Cropping system	1	272 583
Sorghum x cropping system	2	1 103 262
Replications	3	578 986
Error	13	482 220

**Significant at 1% level *Significant at 5% level

Table A35. Analysis of variance for separated plant parts, physiological maturity, irrigated.

Source of variation	d.f.	SORGHUM VEG. PARTS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	8 474 864**	417.10**	61.522**	887.58*
Cropping system	2	50 112	223.59*	3.339	1 153.25*
Sorghum x cropping system	4	988 509*	58.63	15.030**	1 026.50*
Replications	3	1 157 415**	122.41	8.473*	648.01
Error	22	231 049	42.42	1.834	243.59

Source of variation	d.f.	SORGHUM HEADS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	2 943 360**	124.43	8.95	21.45
Cropping system	2	61 141	212.58	14.01	113.22*
Sorghum x cropping system	4	1 697 920**	430.51**	27.61*	70.37*
Replications	3	1 530 529*	270.66*	19.34	37.81
Error	22	379 392	84.37	6.56	20.99

Source of variation	d.f.	MILLET VEG. PARTS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	287 972	35.5	8.540	965.6
Cropping system	1	1 268 059*	170.8*	78.787**	1 109.2
Sorghum x cropping system	2	622 841	255.0**	9.624	204.8
Replications	3	184 834	80.7	13.305	220.7
Error	17	210 055	30.1	6.479	391.1

Source of variation	d.f.	MILLET HEADS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	1 575 510**	374.36**	26.614**	162.7**
Cropping system	1	1 127 943*	316.78*	9.638	1.0
Sorghum x cropping system	2	367 581	70.53	5.232	35.3*
Replications	3	114 230	16.96	1.164	5.5
Error	17	172 377	54.83	2.284	9.7

**Significant at 1% level *Significant at 5% level

Table A36. Analysis of variance for separated components over both days, irrigated SORGHUM.

Source of variation	d.f.	VEG. PARTS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	167 565	79.98	4.152	222.75
Day	1	11 873 799	1 745.81	19.280	4 799.61
Error I (Rep. x day)	3	3 259 027**	515.10**	17.991**	2 399.80**
Sorghum	2	19 798 091**	3 096.35**	236.057**	6 573.07**
Cropping system	2	174 386	376.64	0.294	798.38
Sorghum x cropping system	4	662 362	186.24*	13.743*	646.50
Day x cropping system	2	107 046	38.52	4.921	448.13
Day x sorghum	2	490 869	992.88**	24.211**	1 512.55
Day x sorghum x crop.syst.	4	516 880	112.69	11.827*	517.15
Error II	45	443 526	72.14	3.680	505.03

Source of variation	d.f.	HEADS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	1 309 487	302.53	15.062	119.28
Day	1	60 665 787**	7 954.13*	622.777**	538.16
Error I (Rep. x day)	3	1 394 001**	302.44*	17.398*	103.72*
Sorghum	2	4 722 050**	1 361.67**	69.523**	585.83**
Cropping system	2	347 213	373.53*	21.047*	371.55**
Sorghum x cropping system	4	2 656 509**	804.33**	42.736**	262.89**
Day x cropping system	2	243 888	13.85	4.283	77.15
Day x sorghum	2	4 555 007**	669.51**	37.735**	394.60**
Day x sorghum x crop.syst.	4	205 369	50.25	3.300	49.13
Error II	46	324 773	82.06	4.608	27.09

**Significant at 1% level *Significant at 5% level

Table A37. Analysis of variance for separated components over both days, irrigated MILLET.

Source of variation	d.f.	VEG. PARTS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	316 016	341.0	5.767	734
Day	1	952 358	763.0	17.264	1 051
Error I (Rep. x day)	3	1 232 086	398.6	27.310*	1 548
Sorghum	2	700 874	85.1	34.378*	1 037
Cropping system	1	484 344	23.8	47.010*	455
Sorghum x cropping system	2	1 574 851	572.0*	0.037	1 399
Day x cropping system	1	650 482	157.8	24.867	534
Day x sorghum	2	364 722	85.7	12.376	1 345
Day x sorghum x crop.syst.	2	195 993	6.6	16.045	495
Error II	30	518 974	167.2	8.763	1 171

Source of variation	d.f.	HEADS mean squares
		dry matter
Replications	3	183 583
Day	1	218 170
Error I (Rep. x day)	3	590 661
Sorghum	2	2 328 230**
Cropping system	1	48 956
Sorghum x cropping system	2	1 399 770*
Day x cropping system	1	1 114 483
Day x sorghum	2	99 103
Day x sorghum x crop.syst.	2	204 117
Error II	28	296 065

**Significant at 1% level *Significant at 5% level

Table A38. Analysis of variance for total treatments, Julian day 188, irrigated.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	526 700	139.99	11.555	2 382.5
Sorghum	2	854 767	1 035.76	13.354	2 385.0
Cropping system	2	2 598 840**	2 037.56*	22.691*	12 378.9**
Sorghum x cropping system	4	204 155	201.98	8.009	1 532.9
Error	22	342 072	546.32	5.763	1 199.4
Millet sole stand vs. mixtures	1	501 200	401.79	11.292	5 767.4*
Error	25	323 160	495.24	5.988	1 197.4

Table A39. Analysis of variance for total treatments, Julian day 193, irrigated.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	2 911 977**	1 065.09**	18.024**	2 984.3*
Sorghum	2	574 370	467.24*	34.565**	1 463.3
Cropping system	2	1 803 601*	2 760.28**	56.671**	7 116.9**
Sorghum x cropping system	4	594 488	289.43*	14.639**	133.2
Error	18	347 322	(16)+ 88.90	(16)+3.106	(16)+672.0
Millet sole stand vs. mixtures	1	21 844	475.37	9.670	3 707.4*
Error	21	(19)+309 473	(19)+108.60	(19)+3.895	(19)+778.1

**Significant at 1% level *Significant at 5% level +Degrees of freedom in parentheses

Table A40. Analysis of variance for total treatments, Julian day 199, irrigated.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	792 717	486.80	11.731	954.2
Sorghum	2	1 461 099	207.10	46.420	5 612.6
Cropping system	2	1 622 852	675.37	28.958	2 154.2
Sorghum x cropping system	4	2 143 088	967.89	75.793	5 551.1
Error	20	3 796 533	1 648.52	88.658	7 870.6
Millet sole stand vs. mixtures	1	3 246 594	3 862.03	63.720	5 732.7
Error	23	3 394 745	1 476.04	80.000	7 112.7

Table A41. Analysis of variance for total treatments, Julian day 206, irrigated.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	1 060 482	282.89	1.491	3 827.3
Sorghum	2	1 460 416	384.09	19.557	1 313.4
Cropping system	2	2 081 131	3 751.78	130.448*	5 480.7
Sorghum x cropping system	4	1 027 810	375.72	39.177	2 660.2
Error	20	2 487 206	1 913.92	37.016	2 001.0
Millet sole stand vs. mixtures	1	599 080	92.71	323.875**	9 563.5*
Error	22	2 333 572	1 760.56	34.771	1 979.0

**Significant at 1% level *Significant at 5% level

Table A42. Analysis of variance for total treatments, Julian day 213, irrigated.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	4 859 220*	1 416.10	65.884	8 652.7*
Sorghum	2	3 166 909	1 101.65	12.602	7 875.4*
Cropping system	2	5 157	455.82	29.950	8 215.2*
Sorghum x cropping system	4	1 376 804	338.33	55.749*	2 542.5
Error	20	1 442 889	658.75	18.170	1 803.3
Millet sole stand vs. mixtures	1	11 164 930*	3 009.21*	388.265**	27 152.8**
Error	23	1 536 477	633.40	21.161	2 737.0

Table A43. Analysis of variance for total treatments, Julian day 220, irrigated.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	9 827 005*	2 776.85*	107.205	5 475.8
Sorghum	2	63 017	344.55	23.373	3 426.0
Cropping system	2	666 041	1 324.72	50.286	7 560.7
Sorghum x cropping system	4	427 626	(1)+1 452.77	(1)+53.354	(1)+ 424.4
Error	14	2 422 068	(10)+ 487.11	(10)+25.705	(10)+2 451.0
Millet sole stand vs. mixtures	1	1 848 263	non est.	non est.	non est.
Error	15	2 296 036			

**Significant at 1% level *Significant at 5% level +Degrees of freedom in parentheses

Table A44. Analysis of variance for total treatments, physiological maturity, irrigated.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	8 340 289*	1 294.81	73.593	1 917.2
Sorghum	2	13 352 547**	613.19	42.089	258.4
Cropping system	2	10 839 944*	1 027.42	125.588*	2 547.5*
Sorghum x cropping system	4	2 436 947	680.87	82.428	728.4
Error	20	2 042 496	380.67	28.370	672.8
Millet sole stand vs. mixtures	1	14 304 835*	945.49	449.991**	424.3
Error	23	2 470 445	469.13	31.347	700.0

Table A45. Analysis of variance for total treatments over all days, irrigated.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	2 271 366	695.12	19.473	799.2
Day	6	483 555 220**	39 178.90**	2 914.278**	83 695.1**
Error I (Rep. x day)	18	4 427 242**	1 127.83	46.548	4 165.5*
Sorghum	2	2 567 035	1 582.43	26.256	697.9
Cropping system	2	1 791 780	183.83	116.769*	23 372.6**
Sorghum x cropping system	4	1 521 636	267.69	148.534**	2 523.3
Day x cropping system	12	2 911 725	2 019.70**	65.986*	3 848.8
Day x sorghum	12	3 035 718	551.94	41.347	3 575.3
Day x sorghum x crop.syste.	24	1 110 365	(21)+548.40	(21)+27.956	(21)+1 751.2
Error II	134	1 813 946	(128)+682.11	(128)+30.295	(129)+2 410.9

**Significant at 1% level *Significant at 5% level +Degrees of freedom in parentheses

Table A46. Analysis of variance for components, Julian day 188, dryland.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	6 806	111.51	0.260	107.04
Cropping system	2	211 675	145.17	8.383	875.31
Sorghum x cropping system	4	375 705	263.02	8.574*	1 088.67*
Replications	3	408 181	334.14	7.819	998.26
Error	24	147 933	138.36	2.628	398.69

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	281 203	72.98	4.947	1 178.5
Cropping system	1	114 622	197.38	1.010	402.2
Sorghum x cropping system	2	178 237	22.23	6.289	1 036.8
Replications	3	482 380	489.55	7.824	2 305.3
Error	17	469 865	459.81	10.179	1 923.4

Table A47. Analysis of variance for components, Julian day 193, dryland.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	496 497	175.93	4.602	52.86
Cropping system	2	3 144 737**	1 475.10**	22.618**	3 190.00**
Sorghum x cropping system	4	274 957	203.24	3.880	442.02
Replications	3	569 302	581.80**	8.198**	1 262.29*
Error	23	222 684	112.20	1.878	293.97

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	240 762	113.04	1.646	1 026.7
Cropping system	1	3 435 045**	2 147.69*	54.616**	3 646.0
Sorghum x cropping system	2	49 326	19.80	7.371	438.3
Replications	3	377 193	321.15	2.561	726.0
Error	15	503 352	353.68	4.931	1 084.9

**Significant at 1% level *Significant at 5% level

Table A48. Analysis of variance for components, Julian day 199, dryland.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	1 034 702	633.85**	22.33*	808.57
Cropping system	2	417 525	629.39*	2.34	45.90
Sorghum x cropping system	4	126 507	46.96	10.05	438.79
Replications	3	550 181	213.56	1.32	328.62
Error	24	441 592	154.33	4.07	641.73

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	541 217	392.81	1 137.69	2 029.2
Cropping system	1	190 658	650.95	1 245.16	2 759.8
Sorghum x cropping system	2	288 566	388.60	1 124.65	1 745.5
Replications	3	2 181 660	1 465.00	959.18	5 596.3
Error	18	643 618	478.60	922.02	2 361.7

Table A49. Analysis of variance for components, Julian day 206, dryland.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	510 283	215.67	2.797	94.38
Cropping system	2	2 161 888*	1 967.41**	13.121	1 100.27
Sorghum x cropping system	4	86 485	170.72	4.857	177.61
Replications	3	2 570 328*	878.27*	14.666*	1 670.45
Error	18	604 016	213.17	3.711	548.81

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	2 093 389	783.97	10.863	6 287.9
Cropping system	1	15 819	10.07	3.149	14.6
Sorghum x cropping system	2	4 035 482*	2 628.84*	18.777	4 072.8*
Replications	3	115 974	85.44	1.054	101.4
Error	15	751 347	419.11	5.147	823.4

**Significant at 1% level *Significant at 5% level

Table A50. Analysis of variance for components, Julian day 213, dryland.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	1 794 079.	598.69	52.847**	969.11
Cropping system	2	6 364 077**	3 674.57**	18.299	5 217.62**
Sorghum x cropping system	4	645 533	203.60	4.361	929.05
Replications	3	2 382 707*	679.46*	10.289	1 537.78*
Error	24	594 781	181.26	6.904	487.80

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	49 395	72.85	4.583	716.4
Cropping system	1	4 342 455	1 724.37	7.468	1 160.8
Sorghum x cropping system	2	1 683 237	945.55	5.977	2 785.2
Replications	3	2 927 377	1 459.85	8.544	3 233.9
Error	17	1 995 183	717.32	4.944	2 537.5

Table A51. Analysis of variance for components, Julian day 220, dryland.

Source of variation	SORGHUM mean squares		MILLET mean squares	
	d.f.	dry matter	d.f.	dry matter
Sorghum	2	24 276	2	9 526 347*
Cropping system	2	5 807 813**	1	1 166 717
Sorghum x cropping system	4	2 566 472*	2	1 179 037
Replications	3	1 755 773	3	645 049
Error	22	623 491	17	928 865

**Significant at 1% level *Significant at 5% level

Table A52. Analysis of variance for components, physiological maturity, dryland.

Source of variation	d.f.	SORGHUM mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	24 281 964**	2 795.03**	6.486	3 685.24**
Cropping system	2	3 178 373	829.36	20.353	900.34
Sorghum x cropping system	4	198 938	128.20	16.633	90.69
Replications	3	1 041 907	150.88	14.918	374.27
Error	22	2 146 357	465.12	17.999	367.86

Source of variation	d.f.	MILLET mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	10 848 556*	2 495.91*	120.510**	2 172.6
Cropping system	1	5 308 637	651.84	4.012	927.9
Sorghum x cropping system	2	1 918 227	114.39	5.998	425.8
Replications	3	3 068 504	641.64	13.098	2 111.3
Error	14	1 687 003	484.06	9.033	972.7

**Significant at 1% level *Significant at 5% level

Table A53. Analysis of variance for components over all days, dryland.

Source of variation	d.f.	SORGHUM mean squares dry matter	d.f.	nitrogen	phosphorus	potassium
Replications	3	3 573 366*	3	1 359.33*	14.217	2 651.80*
Day	6	67 256 257**	5	5 065.49**	141.439**	4 688.76**
Error I (Rep. x day)	18	999 786	15	308.44	8.808	729.75
Sorghum	2	995 137	2	415.61	24.446*	83.46
Cropping system	2	12 665 945**	2	6 081.56**	17.141	8 959.74**
Sorghum x cropping system	4	1 408 733	4	240.05	6.291	1 300.36*
Day x cropping system	12	1 459 181*	10	579.29**	13.908*	851.02
Day x sorghum	12	4 519 695**	10	834.99**	12.900*	1 127.14**
Day x sorghum x crop.syst.	24	449 852	20	148.42	8.257	33.06
Error II	157	671 045	135	207.59	6.166	453.29

Source of variation	d.f.	MILLET mean squares dry matter	d.f.	nitrogen	phosphorus	potassium
Replications	3	1 095 897	3	515.44	120.466	863.3
Day	6	43 102 318**	5	6 486.72**	158.923	19 551.5**
Error I (Rep. x day)	18	1 494 036	15	785.77	165.875	2 595.0
Sorghum	2	8 488 900**	2	973.55	171.087	2 315.0
Cropping system	1	9 977 602**	1	4 032.00**	72.425	6 125.2
Sorghum x cropping system	2	3 580 980*	2	1 630.91*	132.652	3 908.5
Day x cropping system	6	880 926	5	264.02	238.747	515.0
Day x sorghum	12	2 746 595**	10	641.94	212.802	2 251.9
Day x sorghum x crop.syst.	12	1 024 219	10	498.61	192.305	1 401.7
Error II	113	998 674	96	489.53	178.449	1 672.8

**Significant at 1% level *Significant at 5% level

Table A54. Analysis of variance for separated plant parts, Julian day 220, dryland.

Source of variation	d.f.	SORGHUM VEG. PARTS mean squares dry matter	nitrogen	phosphorus	potassium
Sorghum	2	6 453 859**	2 479.2**	24.318**	977.8*
Cropping system	2	2 500 835**	1 174.5**	4.138	999.0*
Sorghum x cropping system	4	1 324 053*	280.9*	3.101	652.3*
Replications	3	589 769	64.0	1.570	331.2
Error	23	376 670	80.7	1.247	222.3

Source of variation	d.f.	MILLET VEG. PARTS mean squares dry matter	nitrogen	phosphorus	potassium
Sorghum	2	2 535 553**	702.1*	2.736*	6 038.4**
Cropping system	1	284 442	18.2	0.120	105.7
Sorghum x cropping system	2	256 318	24.3	0.351	85.0
Replications	3	502 250	299.9	0.284	912.5
Error	17	375 137	140.2	0.724	516.5

Source of variation	SORGHUM HEADS mean squares d.f.	dry matter	MILLET HEADS mean squares d.f.	dry matter
Sorghum	2	7 164 940**	2	2 243 831**
Cropping system	2	1 411 633**	1	394 607
Sorghum x cropping system	4	711 151*	2	453 749
Replications	3	882 286*	3	125 710
Error	23	233 419	18	195 075

**Significant at 1% level *Significant at 5% level

Table A55. Analysis of variance for separated plant parts at physiological maturity, dryland.

Source of variation	d.f.	SORGHUM VEG. PARTS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	15 079 191**	2 081.2**	2.124	3 922.4**
Cropping system	2	844 863	100.8	36.821	726.9
Sorghum x cropping system	4	395 308	179.3	24.343	81.8
Replications	3	967 331	62.6	16.462	438.3
Error	22	785 770	128.4	14.424	315.4

Source of variation	d.f.	SORGHUM HEADS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	2 376 142	276.6	7.534	65.5*
Cropping system	2	2 117 251	782.8*	2.930	7.2
Sorghum x cropping system	4	693 984	279.7	6.775	28.3
Replications	3	166 465	64.7	0.327	1.94
Error	24	781 159	229.9	5.437	15.4

Source of variation	d.f.	MILLET VEG. PARTS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	3 568 568*	456.5	31.393**	1 812.9
Cropping system	1	2 453 528	75.8	0.359	1 103.9
Sorghum x cropping system	2	547 926	111.4	8.110	311.5
Replications	3	1 456 179	169.4	3.457	2 183.1
Error	15	639 717	178.5	2.979	808.4

Source of variation	d.f.	MILLET HEADS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Sorghum	2	2 334 092*	886.24**	31.688**	110.9
Cropping system	1	468 724	233.62	1.147	8.5
Sorghum x cropping system	2	234 994	70.79	3.486	18.1
Replications	3	463 560	248.97	6.398	24.7
Error	16	388 798	142.24	2.981	12.4

**Significant at 1% level *Significant at 5% level

Table A56. Analysis of variance for separated components over both days, SORGHUM on dryland.

Source of variation	d.f.	VEG. PARTS mean squares dry matter	nitrogen	phosphorus	potassium
Replications	3	239 268	8.76	3.796	166.5
Days	1	488 782	751.08	17.093	296.2
Error I (Rep. x day)	3	1 326 451	118.40	13.396	613.4
Sorghum	2	20 452 146**	4 521.68**	18.582	3 973.5**
Cropping system	2	2 679 972*	765.59**	7.785	1 716.1**
Sorghum x cropping system	4	1 154 534	288.02*	16.883	433.7
Day x cropping system	2	758 977	536.18**	32.139*	19.2
Day x sorghum	2	911 582	85.22	8.734	854.5
Day x sorghum x crop.syst.	4	549 335	170.15	9.342	299.8
Error II	45	576 674	104.01	7.689	267.8

Source of variation	d.f.	HEADS mean squares dry matter
Replications	3	578 106
Day	1	19 034 860**
Error I (Rep. x day)	3	544 664
Sorghum	2	2 194 138*
Cropping system	2	3 485 138**
Sorghum x cropping system	4	997 209
Day x cropping system	2	44 088
Day x sorghum	2	7 410 304**
Day x sorghum x crop.syst.	4	407 282
Error II	47	513 116

**Significant at 1% level *Significant at 5% level

Table A57. Analysis of variance for separated components over both days, MILLET on dryland.

Source of variation	d.f.	VEG. PARTS mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	1 825 488*	337.5	2.858	2 950.5*
Day	1	2 594 498*	3 439.4*	21.299*	5 680.6*
Error I (Rep. x day)	3	154 649	123.4	0.909	167.6
Sorghum	2	5 412 452**	888.9**	26.521**	5 125.9**
Cropping system	1	2 301 744*	86.7	0.044	991.5
Sorghum x cropping system	2	489 994	19.7	3.026	132.5
Day x cropping system	1	638 212	12.7	0.458	311.1
Day x sorghum	2	934 345	302.5	13.111**	1 983.9
Day x sorghum x crop.syst.	2	330 137	119.4	6.304*	290.2
Error II	32	499 159	158.2	1.781	653.4

Source of variation	d.f.	HEADS mean squares
		dry matter
Replications	3	667 530
Day	1	477 914
Error I (Rep. x day)	3	145 194
Sorghum	2	4 349 470**
Cropping system	1	880 971
Sorghum x cropping system	2	651 823
Day x cropping system	1	6 276
Day x sorghum	2	295 919
Day x sorghum x crop.syst.	2	20 050
Error II	34	286 239

**Significant at 1% level *Significant at 5% level

Table A58. Analysis of variance for total treatments, Julian day 188, dryland.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	720 303	821.45	13.124	2 517.3
Sorghum	2	507 569	154.24	12.023	2 489.4
Cropping system	2	2 861 284	2 182.89	35.910	20 712.2**
Sorghum x cropping system	4	905 040	542.17	19.302	2 425.2
Error	23	861 344	732.46	21.167	3 095.4
Millet sole stand vs. mixtures	1	1 256 208	2 370.99	32.873	281.9
Error	26	811 964	695.80	19.595	2 880.1

Table A59. Analysis of variance for total treatments, Julian day 193, dryland.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	1 660 867*	1 415.03	11.715	5 026.4**
Sorghum	2	1 270 672	309.65	8.263	1 107.2
Cropping system	2	10 469 283**	4 893.61**	95.024**	31 150.2**
Sorghum x cropping system	4	634 056	473.61	9.219	1 426.2
Error	20	436 920	271.36	4.401	903.0
Millet sole stand vs. mixtures	1	856 413	38.62	1.035	188.9
Error	23	412 067	297.46	4.123	904.2

**Significant at 1% level *Significant at 5% level

Table A60. Analysis of variance for total treatments, Julian day 199, dryland.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	1 831 447	1 377.40	682.719	3 890.6
Sorghum	2	2 204 840	609.25	885.236	1 003.1
Cropping system	2	1 996 534	583.95	1 149.703	19 186.1**
Sorghum x cropping system	4	1 333 563	1 361.91	638.964	5 344.8
Error	24	1 269 726	603.20	735.622	3 020.5
Millet sole stand vs. mixtures	1	3 074 514	431.75	63.270	19 861.0*
Error	27	1 651 646	697.64	666.224	4 204.0

Table A61. Analysis of variance for total treatments, Julian day 206, dryland.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	3 683 065	874.21	24.102	2 715.7
Sorghum	2	1 658 588	528.50	6.535	2 022.3
Cropping system	2	832 291	780.17	24.258	13 677.5**
Sorghum x cropping system	4	986 493	1 170.01	16.124	2 434.3
Error	16	1 896 600	751.68	14.536	1 567.1
Millet sole stand vs. mixtures	1	393 608	251.05	4.388	4 687.7
Error	19	1 632 248	640.58	12.979	1 329.7

**Significant at 1% level *Significant at 5% level

Table A62. Analysis of variance for total treatments, Julian day 213, dryland.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	7 899 749	2 933.24	27.824	6 682.5
Sorghum	2	686 243	1 057.47	86.011*	2 234.7
Cropping system	2	96 885	349.53	1.761	20 688.5**
Sorghum x cropping system	4	1 795 415	840.36	4.605	1 946.0
Error	23	2 994 647	1 035.16	17.213	2 988.0
Millet sole stand vs. mixtures	1	1 811 453	210.99	1.949	7 657.1
Error	26	3 012 147	1 044.06	19.068	2 990.0

Table A63. Analysis of variance for total treatments, Julian day 220, dryland.

Source of variation	d.f.	mean squares
		dry matter
Replications	3	3 261 336
Sorghum	2	12 247 959**
Cropping system	2	2 429 296
Sorghum x cropping system	4	2 074 799
Error	21	2 052 602
Millet sole stand vs. mixtures	1	809 591
Error	24	1 958 422

**Significant at 1% level *Significant at 5% level

Table A64. Analysis of variance for total treatments, physiological maturity, dryland.

Source of variation	d.f.	mean squares			
		dry matter	nitrogen	phosphorus	potassium
Replications	3	4 537 353	913.53	12.250	1 285.0
Sorghum	2	6 830 778	508.80	37.558	1 621.0
Cropping system	2	6 066 242	332.65	81.344	1 511.1
Sorghum x cropping system	4	6 869 320	787.36	62.829	1 389.9
Error	18	4 483 560	1 126.71	24.455	890.9
Millet sole stand vs. mixtures	1	2 767 982	2 190.10	3.281	29 756.0*
Error	21	4 003 294	1 044.22	24.790	799.5

Table A65. Analysis of variance for total treatments over all days, dryland.

Source of variation	d.f.	mean squares				
		dry matter	d.f.	nitrogen	phosphorus	potassium
Replications	3	6 268 188	3	2 586.33	154.517	6 905.7
Day	6	237 544 700**	5	20 944.60**	328.780	36 384.3**
Error I (Rep. x day)	18	2 922 947	15	1 149.35	114.389	3 057.9
Sorghum	2	2 295 052	2	630.96	220.085	757.9
Cropping system	2	1 090 619	2	2 606.65*	503.826*	91 704.2**
Sorghum x cropping system	4	2 163 182	4	1 349.88	86.626	3 721.1
Day x cropping system	12	3 926 576*	10	1 278.52	158.518	2 463.6
Day x sorghum	12	3 883 249*	10	512.99	154.684	1 963.5
Day x sorghum x crop.syst.	24	2 066 608	20	772.67	126.621	2 189.1
Error II	145	1 945 200	124	748.93	155.633	2 190.2

**Significant at 1% level *Significant at 5% level

Table A66. Analysis of variance for grain yields and yield components, Ashland irrigated.

Source of variation	d.f.	SORGHUM mean squares					
		gr.yield/.5ha	heads/.5ha	yield/head	seeds/head	TSW	gr.yield(LER)
Sorghum	2	27 666 132**	88 923 365	563.19**	2 036 227**	24.92**	0.0858**
Cropping system	2	77 728	408 221 074*	119.59*	64 333	5.19	0.9805**
Sorghum x crop. syst.	4	679 599**	13 999 876	102.27*	86 699	4.25	0.0227**
Replications	3	383 970**	28 021 007	59.19	304 988*	4.22	0.0093
Error	24	54 367	99 154 864	27.68	89 413	1.57	0.0043

Source of variation	d.f.	MILLET mean squares					
		gr.yield/.5ha	heads/.5ha	yield/head	seeds/head	TSW	gr.yield(LER)
Sorghum	2	509 412**	1557 946 900**	1.355	982	1.125**	0.0354**
Cropping system	1	37 511	271 542 081	0.001	2 860	0.282	0.0031
Sorghum x crop. syst.	2	196 163*	67 780 745	5.432	31 182	0.005	0.0128
Replications	3	7 713	5 888 590	0.541	2 952	0.294	0.0049
Error	18	5 841	212 542 667	4.442	26 979	0.182	0.0039

Table A67. Analysis of variance for grain yields and yield components, Ashland dryland.

Source of variation	d.f.	SORGHUM mean squares					
		gr.yield/.5ha	heads/.5ha	yield/head	seeds/head	TSW	gr.yield(LER)
Sorghum	2	553 306*	82 873 360	112.51*	98 785	27.429**	0.0053
Cropping system	2	3 053 203**	1646 813 300**	243.88**	750 218**	8.867*	2.0940**
Sorghum x crop. syst.	4	141 402	92 335 405	25.19	98 420	15.609**	0.0091
Replications	3	186 170	254 498 980	13.33	62 631	7.532*	0.0293*
Error	24	157 540	86 740 779	26.47	44 805	2.206	0.0094

Source of variation	d.f.	MILLET mean squares					
		gr.yield/.5ha	heads/.5ha	yield/head	seeds/head	TSW	gr.yield(LER)
Sorghum	2	411 700	327 364 270	19.76	106 428	0.5717	0.2061
Cropping system	1	29 782	111 231 718	1.68	20 522	1.1266	0.0448
Sorghum x crop. syst.	2	156 946	166 109 660	29.19	128 175	0.8517	0.1338
Replications	3	120 015	1235 561 400*	9.65	61 957	0.2905	0.0503
Error	18	145 161	377 773 082	18.76	95 248	0.3046	0.0937

**Significant at 1% level *Significant at 5% level

Table A68. Analysis of variance of total treatments for grain yields, Ashland.

Source of variation	d.f.	IRRIGATED mean squares grain yield (kg/.5ha)	IRRIGATED mean squares grain yield (LER)	DRYLAND mean squares grain yield (kg/.5ha)	DRYLAND mean squares grain yield (LER)
Replications	3	1 066 558**	0.011233	349 502	0.00245
Sorghum	2	1 709 456**	0.020775	737 923	0.16399
Cropping system	2	6 308 641**	0.006371	13 838 383**	0.07097
Sorghum x cropping system	4	468 361	0.008730	623 562	0.12427
Error	24	161 106	0.006586	572 481	0.09394
Millet sole stand vs. mixtures	1	3 534 572**	0.000000	461 112	0.04777
Error	27	162 210	0.005950	514 773	0.08353

Table A69. Analysis of variance for canopy heights.

Source of variation	d.f.	IRRIGATED mean squares Sorghum	IRRIGATED mean squares Millet	DRYLAND mean squares Sorghum	DRYLAND mean squares Millet
Sorghum	3	570.03**	26.04	906.05**	7.04
Cropping system	2	72.53	(1)+60.17	40.11	(1)+32.66
Sorghum x cropping system	4	10.28	(2)+23.29	63.11*	(2)+38.79
Replications	3	34.25	28.67	17.81	12.04
Error	24	24.17	(18)+15.81	22.46	(18)+24.01

**Significant at 1% level *Significant at 5% level +Degrees of freedom in parentheses

Table A70. Analysis of variance for total yields.

Source of variation	d.f.	GARDEN CITY mean squares		ST. JOHN mean squares	
		Yield	LER	Yield	LER
Replications	3	563 306	0.164	259 878	0.053
Sorghum	2	3 283 408**	0.634*	1 334 117	0.007
Cropping system	4	3 327 942**	(1)+0.045	824 833*	(1)+0.040
Sorghum x cropping system	4	993 498	(2)+0.016	394 034	(2)+0.086
Error	19	451 720	(10)+0.152	(23)+163 765	(14)+0.041
Millet sole stand vs. mixtures	1	296 561		410 595	
Error	22	420 309		(26)+148 791	

**Significant at 1% level *Significant at 5% level +Degrees of freedom in parentheses

Table A71. Analysis of variance for grain yields and yield components, comparison dryland-irrigated.

Source of variation	d.f.	SORGHUM mean squares					
		gr.yield/.5ha	heads/.5ha	yield/head	seeds/head	TSW	gr.yield(LER)
Replications	3	75 109	134 157 520	11.12	68 626	1.117	0.02592
Water	1	50 845 222**	5209 928 520**	6 275.17**	11 541 707**	25.383	0.41861**
Error I (Rep. x water)	3	494 413**	148 362 470	61.10	298 994**	10.640*	0.01268
Sorghum	2	1 822 679**	34 243 143	432.67**	936 294**	28.058**	0.04762**
Cropping system	2	1 911 961**	1846 951 600**	78.62	305 904*	13.803**	2.96970**
Sorghum x crop. syst.	4	335 136*	53 964 430	46.63	9 053	17.425**	0.01790*
Water x crop. syst.	2	1 218 970**	205 808 380	284.85**	508 647**	0.253	0.10476**
Water x sorghum	2	1 496 760**	137 553 580	243.03**	1 198 719**	24.390**	0.04349**
Water x sorghum x cropping system	4	485 865**	52 370 850	80.83*	173 066*	2.432	0.01393
Error II	48	105 953	92 947 821	27.07	67 101	1.886	0.00684

Source of variation	d.f.	MILLET mean squares					
		gr.yield/.5ha	heads/.5ha	yield/head	seeds/head	TSW	gr.yield(LER)
Replications	3	35 441	644 622 370	3.56	26 592	0.363	0.03379
Water	1	14 510 881**	7202 040 730*	532.83**	2 841 063**	2.658*	0.12597
Error I (Rep. x water)	3	92 788	596 827 670	6.63	38 317	0.222	0.12597
Sorghum	2	903 484**	1591 584 400**	14.68	59 282	0.443	0.22294*
Cropping system	1	223	17 593 654	0.87	19 418	1.268*	0.01222
Sorghum x crop. syst.	2	350 799*	35 264 904	27.57	141 601	0.463	0.11453
Water x crop. syst.	1	67 071	365 180 147	0.81	4 000	0.141	0.03564
Water x sorghum	2	17 629	293 726 760	6.44	48 128	1.254*	0.03988
Water x sorghum x cropping system	2	2 310	198 760 502	5.05	17 757	0.394	0.03204
Error II	36	101 781	295 157 875	11.60	61 113	0.243	0.04877

**Significant at 1% level *Significant at 5% level

Table A72. Analysis of variance for grain yields and yield components, Garden City.

Source of variation	d.f.	SORGHUM mean squares					
		grain yield	LER	heads/.5ha	yield/head	seeds/head	TSW
Sorghum	2	1 906 604**	0.468**	616 204 350**	1 384.3**	1 754 446**	84.6
Cropping system	2	294 613	(1)+0.025	13 269 013	423.7	494 091	14.0
Sorghum x crop. syst.	4	335 830	(2)+0.022	447 718 780**	(3)+295.8	(3)+465 232*	5.7
Replications	3	208 098	0.033	52 206 517	186.2	191 332	8.7
Error	19	134 300	(10)+0.046	77 983 580	(17)+100.9	(17)+123 842	(20)+26.1

Source of variation	d.f.	MILLET mean squares					
		grain yield	LER	heads/.5ha	yield/head	seeds/head	TSW
Sorghum	2	5 105	0.042	482 754 660	32.04	140 425	0.975
Cropping system	1	12 276	0.127	1 221 566 929*	27.93	189 886	0.415
Sorghum x crop. syst.	2	3 451	0.005	356 969 180	25.76	131 525	0.054
Replications	3	43 391**	0.153	449 212 670	4.01	9 071	1.260*
Error	16	7 783	0.066	190 377 795	21.46	102 644	0.315

Table A73. Analysis of variance for grain yields and yield components, St. John.

Source of variation	d.f.	SORGHUM mean squares					
		grain yield	LER	heads/.5ha	yield/head	seeds/head	TSW
Sorghum	2	803 099**	0.016	1 567 568 200**	851.0**	1 103 989**	1.78
Cropping system	2	394 722*	(1)+0.027	87 147 540	163.4*	104 594	51.95**
Sorghum x crop. syst.	4	36 843	0.011	41 895 125	33.5	37 042	4.67
Replications	3	38 217	0.019	58 760 363	31.9	54 754	10.75
Error	23	80 520	(14)+0.032	(24)+93 586 277	37.1	44 025	(24)+7.98

Source of variation	d.f.	MILLET mean squares					
		grain yield	LER	heads/.5ha	yield/head	seeds/head	TSW
Sorghum	2	17 722	0.009	807 389 700	0.44	1 287	0.93*
Cropping system	1	17 759	0.006	987 609 291	0.34	7 847	2.73**
Sorghum x crop. syst.	2	115 038	0.038	5 792 051 000	0.88	7 140	0.52
Replications	3	363 766	0.041	5 037 879 700	8.03	52 969	0.09
Error	18	132 591	0.051	4 735 197 376	3.42	21 011	0.19

**Significant at 1% level *Significant at 5% level +Degrees of freedom in parentheses

GROWTH, NUTRIENT UPTAKE AND GRAIN YIELDS OF INTERCROPPED SORGHUM [*SORGHUM BICOLOR* (L.) MOENCH] AND PEARL MILLET [*PENNISETUM AMERICANUM* (L.) LEEKE]

by

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ABSTRACT

Intercropping sorghum [Sorghum bicolor (L.) Moench] and pearl millet [Pennisetum americanum (L.) Leeke] has been an important and successful traditional cropping method. Traditionally, large differences between the growth cycles of the crops are used and yield increases compared to monocultures are obtained. To make mechanical farm operations possible, only relatively small differences between growth cycles of the crops can be used. A field experiment was designed to observe the influence of temporal differences in development of sorghum and millet and different cropping patterns (cropping systems) on plant growth, nutrient uptake, and grain yields of sorghum and pearl millet.

Three sorghum hybrids with expected growth cycles from 90 to 110 days were planted in sole stands, in alternate rows and mixed within the row with a pearl millet hybrid. Sole stands of millet were included. The experiment was planted at Manhattan, St. John, and Garden City, Kansas. At Manhattan, a dryland and an irrigated study were planted. At all locations, yields and yield components were determined. Dry matter on N, P, and K accumulation over the growing season and canopy heights were determined in Manhattan.

At Manhattan under irrigation, millet performed equally in the early stages regardless of the intercropping partner. From about flowering on, millet intercropped with the early sorghum hybrid had consistently highest values for dry matter, N, and P accumulation. Millet in within-row mixtures with sorghum had highest dry matter, N, and K accumulation until one week before flowering of millet. From about middle of grain filling

on, millet in alternate rows had highest dry matter and N accumulation followed by within-row mixtures and sole stands. P uptake of millet was always highest in sole stands. During the second half of grain filling, significant differences developed between head weights and N, P, and K accumulation in the heads depending on the sorghum intercropped with. Highest values were for millet intercropped with the early, followed by the medium and the late sorghum. Dry matter and N accumulation by the heads and vegetative parts became significantly highest in alternate rows, followed by within-row mixtures and sole stands. Grain yields were not dependent on cropping system, but on sorghum hybrid intercropped with, being significantly higher when intercropped with the early hybrid than when intercropped with the medium or the late sorghum.

Sorghum had highest values for dry matter and N accumulation until one week before millet flowering in alternate rows, thereafter dry matter, N, P, and K accumulation values were highest in sole stands. During grain filling, however, sorghum in alternate rows and within-row mixtures had higher dry matter, N, and P accumulation than in sole stands. All sorghum hybrids had similar growth and nutrient uptake until about 60-70 days after emergence, thereafter the late and medium hybrid had higher growth and nutrient uptake than the early one, as a result of higher head weights of the medium and the late sorghum. Grain yields did not depend on cropping systems.

Up to one week before millet flowering, total dry matter production, N, and P uptake was significantly higher in mixtures than in sole stands of sorghum. Thereafter, no consistent and significant differences occurred among cropping systems. Sorghum hybrids generally did not have

any significant influence on dry matter and nutrient uptake except at physiological maturity, when treatments with the longer growing sorghums had higher dry matter accumulation than those with the early one. Total grain yields were significantly highest in sole stands of sorghum followed by sorghum/millet mixtures and sole stands of millet (significantly lowest). Significantly higher grain yields were obtained from treatments with the medium sorghum than from those with the early and the late one. Grain yields on land equivalent ration (LER) basis did not differ significantly.

Under dryland conditions in Manhattan, growth and development were similar to under irrigation, although, due to higher competition, significant differences between sorghum hybrids developed earlier than under irrigation. Generative development of the late sorghum hybrid was delayed until sufficient rain fell. Millet growth during grain filling was not dependent on cropping systems.

Due to increased competition compared to the irrigated study, the differences in growth between the early and the two later sorghum hybrids were more distinct than under irrigation. This was also the case with the corresponding millet, meaning that millet was generally more competitive than sorghum.

Grain yields of the late sorghum were significantly higher than those of the medium and the early hybrids as a result of seed weight and seed number per head. Sorghum grain yields were significantly lower in mixtures than in sole stands. Millet grain yields were not dependent on cropping systems or intercropping partners.

Total dry matter, N, and P accumulation was generally not dependent on sorghum hybrids or cropping systems. Potassium uptake was significantly higher in mixtures than in sole stands of sorghum and lower than in sole stands of millet. Total grain yields were significantly lower in mixtures than in sole stands of sorghum. Millet sole yields were not significantly different from mixtures.

At Garden City, sorghum and total grain yields were significantly highest from the early and medium hybrid and lowest from the late. Cropping systems did not have significant influence on yields. Millet yields were not dependent on cropping systems nor sorghum hybrids intercropped with. Total grain yields on absolute, but not on an LER basis were significantly higher in sole stands of sorghum than in mixtures; mixtures not being significantly different from sole millet.

At St. John, millet grain yields were not dependent on cropping systems nor on sorghum hybrids. Grain yields of sorghum and total yields were significantly higher in sole stands of sorghum than in alternate rows, and also significantly higher with the late and the medium compared to the early sorghum hybrid.