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GROWTH AND RESOURCE USE OF MAIZE, PIGEONPEA AND MAIZE/PIGEONPEA INTERCROP IN AN OPERATIONAL RESEARCH WATERSHED†

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SUMMARY

Growth and interception of Photosynthetically Active Radiation (PAR) in a maize/pigeonpea intercrop and sole maize and sole pigeonpea crops grown in large plots in an operational research watershed at ICRISAT research centre were compared. Growth and yield of the maize crop, in pure stands and in intercrop, were not significantly different. Efficiency of dry matter production, calculated from the relations between dry matter production and cumulative intercepted PAR, was highest for the maize/pigeonpea intercrop, followed by sole maize and sole pigeonpea, proving the utility of such intercrops in making better use of resources in the Semi-Arid Tropics (SAT).

Intercropping, i.e. growing two or more crops simultaneously on the same land, has been practised for centuries by farmers in tropical and subtropical countries, and the aim of intercropping research is to optimize the use of natural resources including light, water and nutrients (Donald, 1963). Studies by Enyi (1973) showed that maize intercropped with either beans or cowpeas had lower yields than maize intercropped with pigeonpea, probably because the high rates of nutrient absorption by the two legumes coincided with uptake by the maize crop, whereas the greatest nutrient demand by pigeonpea occurred after maize had been harvested.

In most of the Vertisol watershed units at ICRISAT two cropping systems have been tested since 1976, i.e. an intercrop system consisting of medium duration pigeonpea (180–190 days) and short duration maize (85–95 days); and a sequential crop system involving sole maize (105–110 days) followed by a relay crop of sorghum, chickpea or safflower. Maize/pigeonpea intercropping has given a high monetary return on the bed-and-furrow system on deep Vertisol watersheds in both 1976 and 1977 (Krantz, 1979).

The object of the present study was to compare the patterns of growth and light interception in the maize/pigeonpea intercrop and sole maize and pigeonpea crops in the operational research watersheds at ICRISAT, to provide evidence on the performance of the three systems. It should be noted that this was an observational study rather than a replicated experiment.

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MATERIALS AND METHODS

The experiment was conducted during 1978–79 on a deep Vertisol, which is a very fine, clayey, montmorillonitic, calcareous, hyperthermic member of the family of Typic Pallusterts, with an average upper limit of water availability, determined *in situ*, of 0.44 cm^3/cm^3 and a lower limit of 0.27 cm^3/cm^3. The soil, water and crop management system developed for the deep Vertisol watersheds has been described in detail by Krantz *et al.* (1978). A 150-cm broad bed-and-furrow system was established at about 0.4% slope after minor smoothing to erase the micro-relief. The broadbeds were tilled with a multipurpose tool bar immediately after harvesting the last crop. Seed-bed preparation was completed during the dry season, well ahead of planting time, with minimal tillage and soil compaction. Compound fertilizer (18-46-0) was applied at planting at 75 kg/ha, and 107 kg/ha of N was sidedressed for the maize crop. Plant protection was minimal.

All the crops were sown on 12 June 1978. The maize (var. S5154)/and pigeonpea (var. ICRISAT-1) intercrop was planted on 150-cm wide beds, with 2 rows of maize to one of pigeonpea in the centre on each bed and an inter-row spacing of 45 cm. In an adjacent field, two rows of maize (var. SB-23) were planted on each bed with an inter-row spacing of 75 cm. Pigeonpea (var. ICRISAT-1) was sown on the broadbed with an inter-row spacing of 75 cm in a nearby field. Final plant populations established for maize were about 80,000 plants/ha in both the intercrop and sole crop fields, whereas those for sole and intercropped pigeonpea were 80,000 and 40,000 plants/ha respectively. In order to permit more light penetration to intercrop pigeonpea after the maize reached its physiological maturity the maize tops were cut just above ear level by 15 September.

Maize was harvested on 30 September, and above-ground whole plants were sampled at three random plots of 3 m^2 of each crop at 7–10 day intervals, beginning about 25 days after planting. After measuring its height, each plant was separated into leaves, leaf sheaths, petioles, cobs and grain (in the maize), and pods and seeds (in pigeonpea). The leaf area of each plant was determined with a LI-COR leaf area meter (LAMBDA Instruments Corporation, Lincoln, Nebraska†) and plant parts were then dried to constant weight at 65°C in a forced draught oven.

Canopy interception of Photosynthetically Active Radiation (PAR) in all the crops was measured using four quantum sensors (LAMBDA Instruments Corporation) mounted on horizontal bars in a portable framework 150 cm wide × 200 cm long. The frame was placed horizontal and level at the soil surface in each canopy so that the crop rows in a 150 cm wide bed were centred in the frame, siting the frame under the most uniform stand of plants available. Each

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† Mention of commercial products or companies does not imply endorsement or recommendation by ICRISAT.

sensor was then moved across the crop row on the horizontal track provided by the 150 cm steel bar, which was marked at 10 cm intervals so that the sensor could be moved manually from one end to the other in 150 seconds by positioning it for 10 sec at each mark. Each sensor was attached to a read-out integrator (LI-510, LAMBDA Instruments Corporation); after 150 sec the integrated reading was noted and the sensor moved back to the original end. Data for PAR transmission to the soil surface on any given day under any given canopy represent the average of forty readings, i.e. from the four sensors, each replicated ten times. One quantum sensor was mounted above the crop canopy to record the PAR incident on the canopy (I_0) and interception of PAR was calculated using the I_0 and PAR transmission values. Using the framework, canopy interception of PAR was measured at several spots in the field throughout the growing season.

PAR interception data, taken at 7–10 day intervals during the growing season, were plotted and interception for each day calculated. Daily solar radiation data for ICRISAT were used to calculate PAR values for each day from the relation between solar radiation and local PAR (ICRISAT, 1978). PAR intercepted each day and cumulative intercepted PAR for the growing season for each canopy were calculated from daily PAR and data for canopy interception.

RESULTS

Meteorological data for the growing season (Table 1) show that June, July and August were characterized as fairly high rainfall months, August being very wet with low average daily solar radiation. The soil moisture profile was fully recharged and pigeonpea was rarely under moisture stress during November, December and January. Seasonal changes in plant height, Leaf Area Index (LAI) and total dry matter for the sole maize and pigeonpea crops and maize/pigeonpea intercrop (Table 2) present a comparative evaluation of the efficiency of different crops. The intercrop maize, being shorter in duration,

Table 1. *Meteorological parameters during the growing season at the ICRISAT Research Centre*

Month	Average temperature Max. (°C)	Average temperature Min. (°C)	Total precipitation (cm)	Average 24 h winds (km/hr)	Average solar radiation (ly/day)	Average pan evaporation (cm/day)
June	33.1	23.2	18.1	20.3	429	0.36
July	28.9	22.1	22.8	14.9	351	0.45
August	28.0	21.7	51.6	14.3	328	0.36
September	29.6	21.6	8.2	8.7	430	0.42
October	30.5	20.0	7.1	7.2	497	0.52
November	29.2	18.6	1.0	8.4	433	0.43
December	27.2	15.2	0.1	7.9	401	0.47
January	28.5	16.2	0	9.6	431	0.53
February	30.2	18.7	4.1	11.6	425	0.61

Table 2. *Seasonal changes in plant height, leaf area index (LAI) and total drymatter of sole and intercropped maize and pigeonpea*

	Maize			Pigeonpea		
Days after planting	Plant height (cm)	LAI	Total dry matter (g/m²)	Plant height (cm)	LAI	Total dry matter (g/m²)
			Sole-cropped			
26				21	0.1	5
30	32	0.5	16			
37				35	0.2	18
40	72	2.1	195			
46				49	0.2	19
50	137	3.0	333			
58				61	0.4	35
61	196	3.3	628			
68				79	0.8	75
71	203	3.5	650			
77				85	0.9	100
81	206	2.2	902			
83				97	1.1	121
89	184	1.1	813			
90				110	1.0	183
97				108	1.1	188
104				108	1.6	192
111				123	2.3	251
118				144	3.2	411
123				175	3.2	485
130				191	3.4	588
137				190	2.9	555
144				202	2.7	652
151				198	3.0	701
159				200	1.7	741
166				195	1.0	680
172				181	0.7	645
180				178	0.6	731
187				176	0.5	613
194				206	0.3	787
			Intercropped			
27	58	0.6	42	22	0.1	7
34	56	1.7	75	34	0.1	5
41	102	2.8	241	55	0.2	8
48	139	3.8	349	73	0.3	16
55	194	3.7	544	103	0.4	22
62	204	3.6	740	122	0.6	34
69	184	3.1	718	100	0.6	21
76	203	2.7	923	121	0.6	48
93				128	0.5	60
101				126	0.6	73
110				137	0.7	86
117				127	1.1	97
125				153	1.5	209
132				166	1.6	285
139				162	1.2	326
146				168	2.3	302
153				174	2.2	512
158				203	1.9	486
165				183	1.6	442
172				187	1.5	577
179				191	1.1	567
186				187	0.8	606

reached its maximum LAI earlier and produced more dry matter and yields compared with the sole maize crop (3518 and 3500 kg/ha respectively).

Intercropped pigeonpea grew slowly, as reflected by the slow changes in LAI and total dry matter (Table 2). Because of the higher plant population and absence of competition from the companion crop, pigeonpea in pure stands showed better canopy growth. Sole pigeonpea produced 23% of its maximum dry matter by 100 days after planting and 84% by 154 days, compared with 12 and 84% respectively for the intercropped pigeonpea. The yield of sole pigeonpea was 1833 kg/ha and intercropped pigeonpea 1520 kg/ha.

Drymatter distribution in the above-ground plant parts of maize (Fig. 1) showed rapid accumulation of dry matter in the later stages, mostly in the stalk. The bulk of dry matter accumulation in sole pigeonpea (Fig. 2) was in its stems, mostly between 100 and 150 days, after which pods and seeds accumulated a fair amount of dry matter coinciding with rapid leaf senescence.

Dry matter distribution in the maize/pigeonpea intercrop (Fig. 3) demonstrated the useful contribution of the maize crop to total DM for the first 80 days after planting. Even after the maize was harvested pigeonpea did not show an appreciable accumulation of dry matter up to 120 days after planting, and its total dry matter reached only 63% of the maximum at harvest when the stem fraction was the dominant dry matter component.

Seasonal changes in the interception of PAR for the three crops (Fig. 4) show that interception for maize closely followed the pattern of canopy development (Table 2). PAR interception was low, with a slow increase in LAI up to 50 days after planting, maintained at a fairly high rate for the next 30 days after which it declined.

PAR interception in the sole pigeonpea crop showed low values up to about 70 days after planting, when LAI was only about 0.9. Interception increased

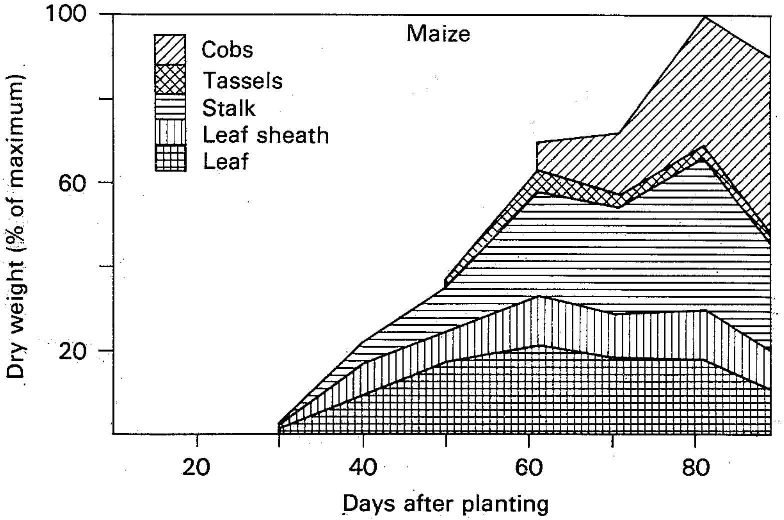

Fig. 1. Dry matter distribution in above-ground parts of maize, expressed as a percentage of maximum dry matter produced.

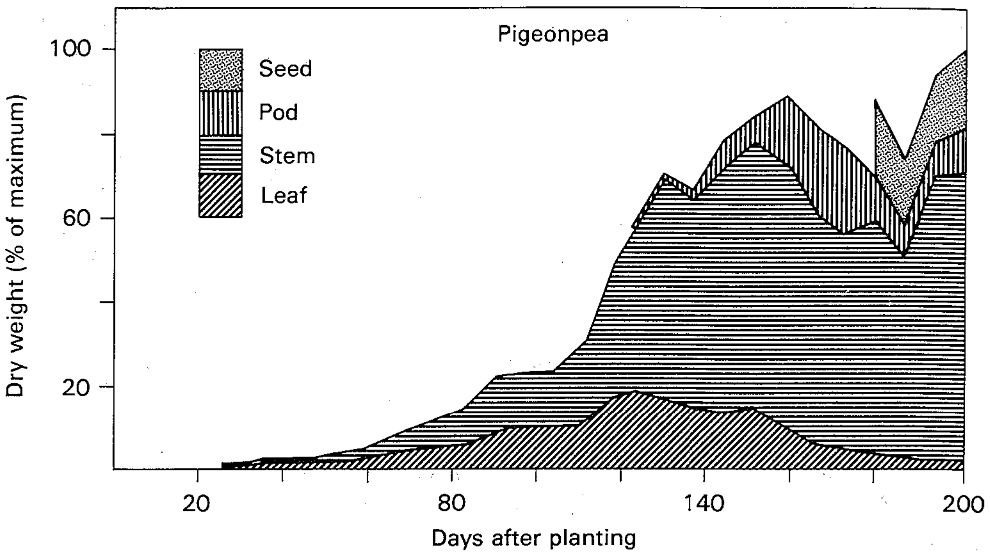

Fig. 2. Dry matter distribution in above-ground parts of pigeonpea, expressed as percentage of maximum dry matter produced.

up to 93 per cent with the steady increase in LAI up to about 130 days, after which increasing leaf senescence contributed to a steady decrease. Seasonal changes in the interception of PAR in the maize/pigeonpea canopy (Fig. 4) showed that the maize/pigeonpea canopy maintained higher levels of interception up to the time of maize harvest because of its higher LAI values. PAR

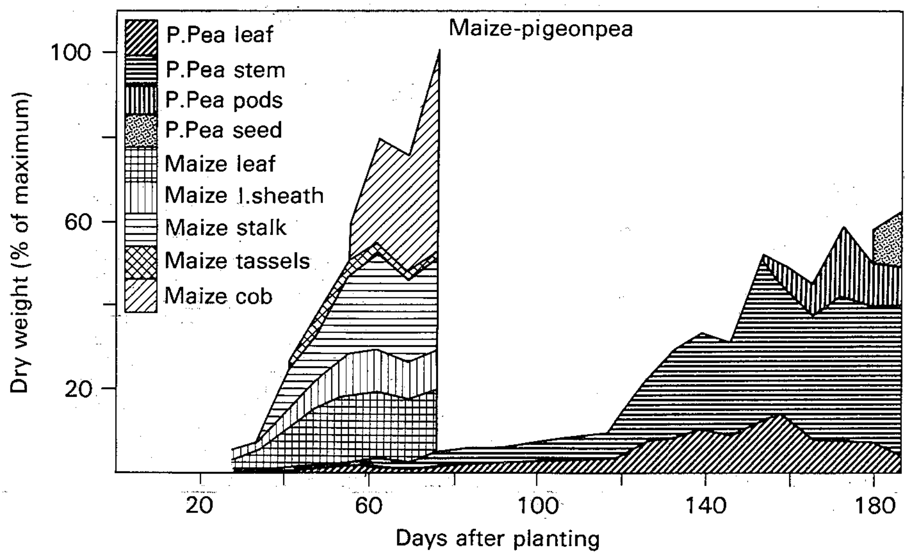

Fig. 3. Dry matter distribution in above-ground parts of maize/pigeonpea intercrop, expressed as percentage of maximum produced for the intercrop total.

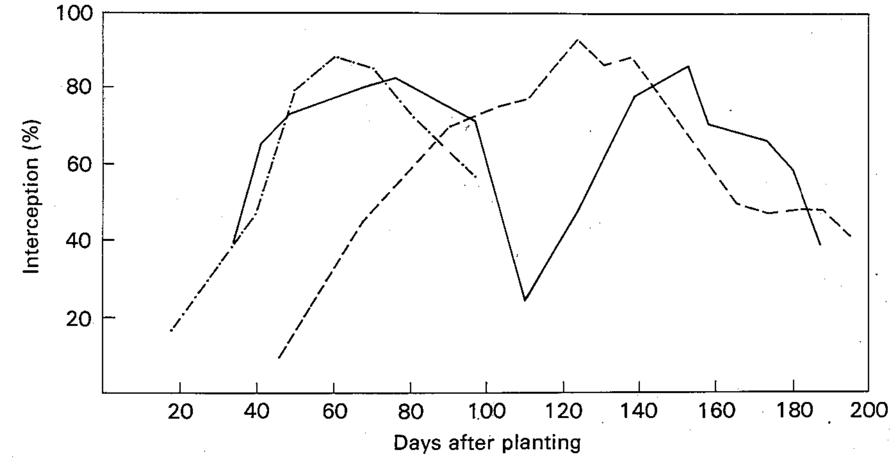

Fig. 4. Seasonal interception of Photosynthetically Active Radiation (PAR) in sole maize (—.—.—.), sole pigeonpea (— — —) and maize/pigeonpea intercrop (———).

interception dropped to about 24% after the maize harvest, but later increased with the accelerating canopy development.

The relations between total dry matter produced and the cumulative intercepted PAR for the three crop canopies are shown in Fig. 5. For the maize/pigeonpea intercrop, the total dry matter is for both crops up to the maize

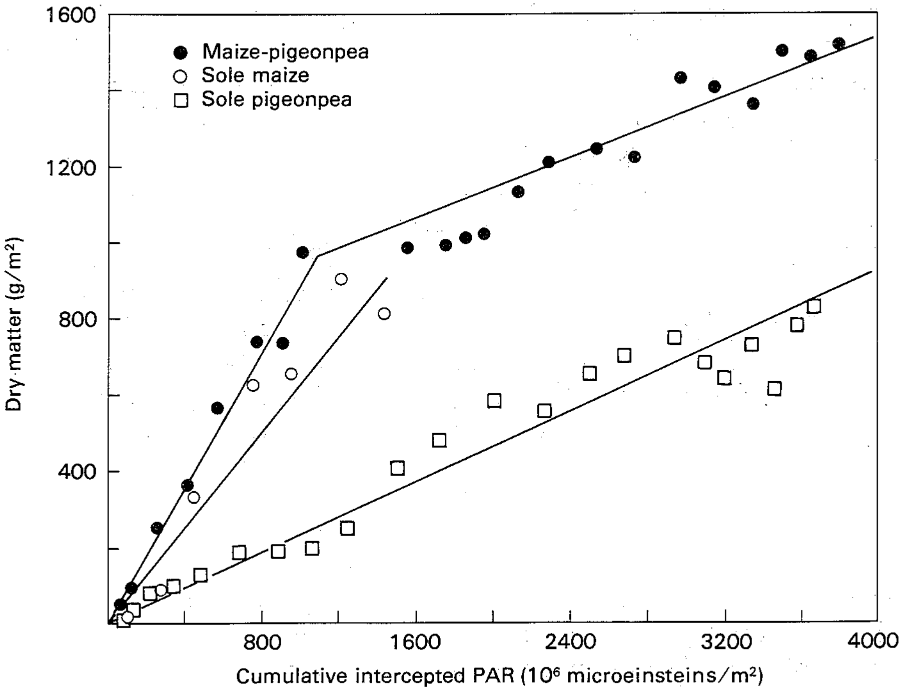

Fig. 5. Dry matter production as a function of cumulative intercepted PAR in sole maize, sole pigeonpea and maize/pigeonpea intercrop.

Table 3. *Relations between cumulative intercepted PAR (X) and dry matter (Y) for different crops*

Crop	Regression coefficient b	SE of b	R^2	t test
Sole maize	0.68	0.04	0.98	16.73**
Sole pigeonpea	0.23	0.01	0.98	36.98**
Intercrop (up to harvest of maize)	0.93	0.02	0.99	46.24**
Intercropped pigeonpea (after harvest of maize)	0.26	0.02	0.94	14.98**

** Significant at P = 0.01.

harvest, after which the total dry matter of maize produced at harvest (923.3 gm/m^2) was added to the dry weight of pigeonpea taken at each subsequent sampling date. Production efficiency (DM produced per unit of intercepted PAR) was very low for the sole pigeonpea crop, and sole maize was also less efficient than the intercrop. The overall efficiency of interception by the maize/pigeonpea intercrop system is immediately clear. For comparison, Alberda *et al.* (1977), Biscoe *et al.* (1975) and Hesketh and Baker (1967) showed that net photosynthesis increased linearly with irradiance between 230 and 1470 microeinsteins/m^2/sec PAR.

Regarding the relation between cumulative intercepted PAR and dry matter for different crops in terms of regression equations (Table 3), the line fitted between cumulative intercepted PAR (x) and dry matter (y) was forced through the origin. Two separate equations have been fitted to describe the radiation conversion efficiency for the intercrop, i.e. up to and after the harvest of maize. The slope of the regression line (regression coefficient b, g/einstein) implies that dry matter production (g) per einstein of PAR intercepted could vary for different crops. It is possible to calculate the growth efficiency for different crops, as defined by Biscoe and Gallagher (1977), using an average calorific value of 17.5 kJ/g and a conversion factor of 4.6 μE per J of sunlight. By this method growth efficiency for maize/pigeonpea intercrop was 7.3% followed by maize and sole pigeonpea with 5.3 and 1.8% respectively, though the intercropped pigeonpea showed a growth efficiency of 2% after harvesting the maize. These calculated growth efficiency values for maize/pigeonpea intercrop are higher than the values reported by Biscoe and Gallagher (1977) for barley and wheat.

DISCUSSION

These data emphasize the usefulness of a maize/pigeonpea intercrop system which takes advantage of the changing growth patterns of pigeonpea and maize. The habit of pigeonpea in pure stands results in a very low utilization of PAR in the first 80 days after planting, and it is logical to modify this situation by growing a short duration cereal crop without any substantial reduction in the legume yield. Analysis of leaf light-response curves and light extinction properties of a wide range of crop species and cultivars by Trenbath (1979) showed that the leaf and canopy properties measured for maize are closest to the predicted optimum for the upper canopy (under the conditions studied). The advantage of intercropping maize and pigeonpea has been shown by the earlier studies by Enyi (1973) and Dalal (1974).

Slow growing legume crops such as pigeonpea, with a low LAI for the first 80 days after planting, seem to show a photosynthetic response to increasing incident light flux much like that of a single leaf, and reach light saturation fairly early. But when grown along with a cereal crop such as maize, the total LAI for the intercrop is high and shaded leaves at the bottom of the canopy can continue to respond to an increase in incident light flux even if leaves high in the intercrop, i.e. of maize, are light-saturated. Thus, as Trenbath suggests, the whole shoot systems respond to increasing light flux with canopy growth up to progressively higher levels, which might explain the higher efficiency of PAR-utilization in intercropped compared with sole pigeonpea. The success of such intercrops has been shown also to be associated with complementarity in time and the possibility of higher plant population pressure, both of which result in greater light interception (Fisher, 1975; Willey and Natarajan, 1978). Radiation interception by the crop is often correlated with growth rate early in the season (Biscoe and Gallagher, 1977; Williams *et al.*, 1965) and with yields (Monteith, 1977; Duncan *et al.*, 1973).

It appears that the time course of PAR penetration through the maize to the pigeonpea canopy is an essential component in the efficiency of PAR-utilization. Part of the problem associated with increasing shade due to the maize crop was overcome by cutting the maize tops just above ear level at physiological maturity, which could have helped in removing major shade competition from the pigeonpea, which was then about 125 cm high and showed faster subsequent growth by better lateral spread of its apical branches. What would happen if population pressure from the cereal crop could be reduced to enable pigeonpea to make better use of PAR? The answer to this question would largely depend on the degree of yield reduction in the cereal, and the advantage that would be gained for pigeonpea.

As an alternative, Willey and Natarajan based their studies on sorghum/pigeonpea and suggested that the pigeonpea genotype could be improved for efficiency of light use. It will also be important to study the shade tolerance associated with different genotypes of pigeonpea and characteristics related to the sudden response to PAR once the cereal crop is removed. An ability to adapt quickly to changes in light level seems to be a desirable characteristic.

In conclusion, data from the operational research watersheds for these three cropping systems show the utility of adopting a maize/pigeonpea intercrop and seem to re-emphasize the results from small plot intercropping trials. There is still scope to improve upon this system, and increase and stabilize agricultural production for the arid and semi-arid areas of the world, where such cropping systems are increasingly popular.

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