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Research Article

Screening of Maize Hybrids under Maize/Soybean Intercropping Based on Their Combining Abilities and Multiple Cropping Components

¹Y. Yuwariah, ²J. Supriatna, ³A. Nuraini, ⁴Nyimas Popi Indriani, ⁵A.T. Makkulawu and ³D. Ruswandi

¹Laboratory of Crop Production, Faculty of Agriculture, Padjadjaran University, 40600 Bandung, Indonesia

²Faculty of Agriculture, University of Garut, Indonesia

³Laboratory of Plant breeding and seed technology, Faculty of Agriculture, Padjadjaran University, Indonesia

⁴Faculty of Animal Husbandry, Padjadjaran University, Indonesia

⁵Indonesian Cereals Research Institute, Maros, Indonesia

Abstract

Background and Objective: Maize/soybean multiple cropping was applied to increase productivity of maize and soybean altogether in West Java, Indonesia. The objectives of the research was to estimate the combining ability of the parental inbred lines of Indonesian maize and to select their hybrids which suitable for intercropping with soybean. **Materials and Methods:** An experiment was set up in Arjasari-Kabupaten Bandung, West Java from December, 2015 up to March, 2016 to study combining ability and to screen new maize hybrid and their parental inbreds for multiple cropping with soybean. To study the genetic materials, they were planted based on split plot arrangement. This was replicated twice with the main plot consisting of maize sole cropping and maize/soybean multiple cropping, whereas, the subplots were one hundred twenty four genotypes. **Results:** Inbreed #1 was the best combiner for early maturity, plant height and seed weight per plant. There were 11 hybrids adapting to cultivate under maize/soybean multiple cropping based on LER, CRm, CRs and STI and performing higher seed weight per plant than commercial hybrids. Those hybrids were hybrid 24, 26, 40, 56, 61, 62, 75, 78, 81, 90 and #100. **Conclusion:** These hybrids were suggested to be evaluated for their stability and adaptability under maize/soybean multiple cropping for different location and seasons.

Key words: Competitive ratio, combining ability, land equivalent ratio, multiple cropping, stress tolerance index

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Corresponding Author: D. Ruswandi, Laboratory of Plant breeding and seed technology, Faculty of Agriculture, Padjadjaran University, 40600 Bandung, Indonesia

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Maize and soybean are two important crops for Indonesian people nowadays. Maize has an important role in Indonesia modern agro-industry. Maize is used as: Corn starch and high fructose corn syrup for food industry, feed for live stock industry and ethanol for agro industrial product. On the other hand, soybean is among the most important legumes for making tempeh and tofu that are among the significant daily diets of Indonesian people.

Maize based intercropping, such as maize/soybean intercropping can increase crop productivity of the two commodities. The system use more effective consumption of supplies including water, nutrient and light¹⁻⁴, thus stimulating green and beneficial agriculture. The advent of the cropping system was reported by some researchers as the following: (i) To rise the productivity of land uses due to the ability to catch more sunlight than by growing alone, (ii) To increase nutrient and water use efficiencies, (iii) To enhance ecological services, (iv) To extend the growing season by relay planting of pea for cool season and maize for warm season, (v) To decrease the risk of harvest failure in modern agriculture due to biotic stress, low yield, soil degradation and environmental deterioration, (vi) To decrease soil respiration and reduce carbon emission in arid land^{2,3,5-8}.

Some factors need to be considered in applying maize/soybean intercropping. These factors include maize cultivar, location, strip width and competition on sources⁹⁻¹². Gao *et al.*⁹ reported that above all yield rise of 65 and 71% in a system of one and two rows of highly density of cultivation maize rotated using three rows of soybean. Both crops are cultivated as singular crops or monocrops. Monzon *et al.*¹⁰ concluded their studies that: (i) Maize yield in double crop was comparable to that of arranging maize alone, whereas soybean yield in double crop was decreased. The decrease was equal to that growing soybean solely, (ii) Maize and soybean yields for relay crop and intercrop were lower than their relevant sole crops, (iii) the land equivalent ratio (LER) was greater than 1.00 in 100, 86 and 61% for maize-soybean double crop, relay crop and intercrop, respectively. Lv *et al.*¹² revealed that competition between above-ground and/or below ground plant in maize soybean intercropping is an important factor of intercropping advantage. The competition in this intercropping system was due to nutrients, water and sunlight and that intercropping is not advantageous in the absence of competition.

A useful parameter to select inbred lines and their cross combination is using the analysis of combining ability. This parameter is also important to study the various

quantitative characters like that are involved in gene action. Both general and specific combining ability are major indicators for selecting superior parental lines for use in crossing combinations. It is an important step in developing hybrid varieties of maize with a good economical values and at the same time tolerant to biotic and abiotic stress conditions¹³⁻¹⁸. Furthermore, GCA and SCA was used as genetic parameters to select sweet corn that are adaptable under sweet corn/chilli pepper multiple cropping¹⁹.

In Indonesia, breeding programs for developing hybrid cultivars of maize that are suitable for intercropping have been initiated¹⁹. Superior parental inbred lines which high yield and high nutrient composition by hybridization and mutation has been developed²⁰⁻²³. However, the information on combining ability of these inbred lines and their hybrid performance in maize/soybean intercropping systems have not yet been explored. Among the objectives of the research was to estimate the combining ability of the parental inbred lines of Indonesian maize and to select their hybrids which suitable for intercropping with soybean.

MATERIALS AND METHODS

Genetic material and evaluation site: The study evaluated 124 genotypes of maize seeds including 15 Unpad inbred lines, 105 F₁ developed through diallel mating design by Griffing II and 4 commercial hybrids (Bisi-2, Bisi-816, Bisi-18 and Pertiwi-3). In addition, Argomulyo commercial soybean cultivar was used for maize-soybean intercropping. Evaluation was performed from November, 2015 up to February, 2016 in Arjasari, West Java, Indonesia at 750 m asl. (above sea level). This climate is a type C3 based on the classification by Oldeman.

Statistical analysis: The seed materials were planted in a split plot arrangement consisting of 2 replications with the cropping system as the main plot (maize sole cropping system and maize-soybean intercropping system) and maize genotypes as the subplot, thus the genotypes in the subplot were laid on a randomized completely block design. The traits observed were days to tassel, days to ear, plant height, seed weight per plant and yield per plot.

Data analysis covered the estimation of combining ability and evaluation of maize hybrid in an intercropping system with soybean. The ANOVA was done for the average data of maize sole cropping system. Diallel crosses were analyzed based on Griffing II method²⁴, which estimates General Combining Ability (GCA) of maize inbred and Specific Combining Ability (SCA) of superior hybrids. F-test was used to estimate the significance of GCA, SCA and the hybrids.

Screening of adaptive maize hybrid performance in intercropping with soybean was estimated using least significant increase (LSI) following by Petersen²⁵. Thus, productivity of hybrid in intercropping with soybean was determined based on Land Equivalent Ratio (LER) according to Willey²⁶ and competitive ratio of maize hybrid following Dhima *et al.*²⁷. On contrary to the evaluation of maize hybrid performance, evaluation of tolerant soybean to maize under maize-soybean cropping system was estimated based on Stress Tolerance Index (STI)²⁸.

RESULTS AND DISCUSSION

General and specific combining ability of maize: Analysis of variance (ANOVA) of combining ability for the studied traits were presented in Table 1. The results showed that GCA value was significantly different for days to tassel, days to ear, plant height and seed weight per plant. SCA value however significantly differs for all the traits. These results indicated the importance of both additive and non-additive gene effect in the inheritance of the studied traits. Some researcher mentioned the important of GCA and SCA for yield component traits in both yellow and white maize whether in normal and under stress conditions^{13-15,17,18}.

Combining ability information helps to select inbred lines that potentially produce progeny for the expected trait. It provides knowledge on the mechanisms of genetic inheritance that control quantitative traits such as morphological and physiological traits as well as yield component and yield. Knowledge on the combining abilities of inbred lines can be used to identify hybrids for commercial use¹⁵. Selection of inbred lines maize based on combining ability to produce maize hybrids with high yield potential and tolerant to biotic and abiotic stresses reported by many breeders^{13-15,17,18,21,22}. This implied that in determining hybrids with high yield potential, the genetic structure of inbred lines and their combining ability play important roles. GCA effect shows that hybrid performance mainly controlled by additive gene effect, whereas SCA effect shows that hybrid performance mainly controlled by non-additive gene effect including dominance and epistatic genetic effects¹⁸.

The GCA values for the studied traits were presented in Table 2. Data showed that GCA value varies for all inbred lines. Variation of GCA value indicated performance of different lines regarding different testers. The expected value of GCA for days to tassel, days to ear and plant height is negative, whereas GCA for seed weight per plant and yield per plot is positive. Negative value showed that specific

Table 1: Analysis of variance (ANOVA) of combining ability

Source of variations	Degree of freedom	Days to tassel	Days to ear	Plant height	Seed Weight /plant	Yield/plot	F.05
Replication	1	58.53*	4.38*	0.13	6.30*	5.31*	3.92
Genotype	119	51.03*	39.94*	7.05*	19.29*	1.72*	1.35
GCA	14	86.06*	68.60*	20.49*	34.29*	1.52	1.78
SCA	105	46.36*	36.12*	5.26*	17.28*	1.75*	1.36
Error	119						
Coefficient of variance		1.09	1.22	4.09	7.79	31.42	

*Significant based on F-test at 5%

Table 2: General Combining Ability (GCA) estimates and means of observed traits

Genotypes	Days to tassel		Days to ear		Plant height		Seed weight/plant		Yield/plot	
	GCA	AVG	GCA	AVG	GCA	AVG	GCA	AVG	GCA	AVG
(1) DR 10	-2.12**	60.5	-2.1**	62	-19.54**	248.33	8.53**	159.57	-213.49	1200
(2) MDR 9.1.3	-0.94**	65.5	-1.22**	67	0.79	287.5	-8.79**	74.33	260.33	1850
(3) MDR 7.4.1	-0.41**	59.5	-0.54**	60.5	1.56	288.34	10.50**	203.99	174.16	2400
(4) DR 18	0.88**	59.5	0.9**	61	4.99*	282	-6.85**	83.68	-149.67	610
(5) MDR 14.2.2	0.18	58.5	0.2	60	-3.11	277	-18.63**	68.27	261.80	1825
(6) DR 8	0.41**	58.5	0.43**	60	3.14	277.5	-9.04**	92.33	41.80	2675
(7) MDR 3.1.4	1.06**	58.5	1.08**	60	8.63**	302.5	-1.18	102.37	222.10	2450
(8) MDR 4.8.8	2**	57.5	2.02**	59	14.63**	322.75	28.17**	222.89	-123.49	1450
(9) G 673	1.18**	59.5	1.23**	61	9.84**	302.98	-10.06**	144.45	-370.84	950
(10) G 20133077	-0.32**	58.5	-0.27*	60	-9.31**	192.5	3.17	185.17	-249.08	2465
(11) MDR 18.8.1	-0.09	57.5	-0.04	59	9.26**	316.8	-6.31**	70.10	152.10	2375
(12) MDR 7.1.9	-1**	58	-0.95**	59.5	-8.56**	243.71	6.38**	155.47	-223.20	1300
(13) MDR 1.1.3	-0.29**	56.5	-0.27*	58	-9.94**	206.67	0.34	165.76	86.80	2575
(14) MDR 18.5.1	-0.59**	56.5	-0.57**	58	1.06	288.4	-16.05**	54.89	-72.90	750
(15) G 203 – 1	0.06	55.5	0.11	57	-3.44	230.05	19.83**	132.49	203.57	750

*Significant based on F-test at 5%, **Significant based on F-test at 1%, Yellow show selected inbred line based on GCA

Table 3: SCA and mean of days to tassel, days to ear, plant height, seed weight per plant and yield per plot for selected hybrids

Hybrids	Code	Days to tassel		Days to ear		Plant height		Seed weight per plant		Yield per plot	
		SCA	Means	SCA	Means	SCA	Means	SCA	Means	SCA	Means
DR 10×MDR 3.1.4	6	-1.44**	56.5	-1.4**	58	-9.64**	267	16.54**	190.4	907.1**	4100
DR 10×MDR 4.8.8	7	1.62**	60.5	1.66**	62	15.48**	298	46.27**	249.4	1303**	4150
DR 10×G 673	8	0.44**	58.5	0.46**	60	29.43**	308	22.18**	187.1	1450**	4050
DR 18×MDR 18.8.1	10	-4.79**	52	-4.78**	53.5	-17.5**	260	21.2**	189.9	577.1*	3700
DR 10×G 203-1	14	1.56**	58.5	1.57**	60	-13.1**	252	10.7**	205.5	675.6**	3850
MDR 9.1.3×G 20133077	22	0.76**	58.5	0.57**	59.5	23.26**	303	10.82**	171.6	1054**	4250
MDR 9.1.3×MDR 18.8.1	23	0.53**	58.5	0.34*	59.5	-27**	271	28.64**	180	553.2*	4150
MDR 9.1.3×MDR 7.1.9	24	-2.56**	54.5	-2.75**	55.5	11.68**	292	51.75**	215.8	953.5**	4175
MDR 7.4.1×DR 18	28	0.03ns	59.5	-0.28ns	60.5	-0.98ns	293	73.42**	243.5	966.2**	4175
MDR 7.4.1×MDR 14.2.2	29	-7.26**	51.5	-7.57**	52.5	-26**	260	12.78**	171.1	554.7*	4175
DR 18×MDR 14.2.2	40	-3.56**	56.5	-3.51**	58	-6.31*	283	25.92**	166.9	503.5*	3800
DR 18×MDR 7.1.9	47	1.62**	60.5	1.63**	62	14.13**	298	33.3**	199.3	663.5**	3475
MDR 14.2.2×G 673	54	1.15**	61.5	1.16**	63	13**	308	40.19**	178	1675**	4750
MDR 14.2.2×G 20133077	55	7.65**	66.5	7.66**	68	19.65**	295	23.93**	174.9	577.9*	3775
MDR 14.2.2×MDR 18.8.1	56	-2.59**	56.5	-2.57**	58	-5.58*	288	67.37**	208.9	926.8**	4525
MDR 3.1.4×MDR 18.5.1	76	1.03**	60.5	1.07**	62	3.38ns	301	60.94**	210.2	816.5**	4150
MDR 4.8.8×G 673	78	-1.68**	60.5	-1.66**	62	-2.24ns	310	40.48**	225	1285**	3975
MDR 4.8.8×G 203-1	84	-0.56**	60.5	-0.54**	62	-3.13ns	296	26.65**	241.1	885.6**	4150
G 673×G 20133077	85	-4.35**	55.5	-4.37**	57	-13.3**	275	19.31**	178.9	585.6*	3150
MDR 18.5.1 ×G 203-1	105	0.03ns	58.5	0.04ns	60	-2.89ns	283	9.11**	179.3	710**	4025

*Significant based on F-test at 5%, **Significant based on F-test at 1%, Yellow show selected hybrid based on SCA

inbred line has the potential to produce progeny that have early maturity and short plant height, whereas positive value showed that particular inbred line has the potential to produce progeny that have high yield components. Six inbred lines were selected based on days to tassel and days to ear (inbred 1, 2, 3, 10, 13 and #14), 4 inbred lines were selected based on plant height (1, 10, 12 and #13) and 5 inbred lines were selected based on seed weight per plant (1, 3, 8, 12 and #15). Inbred #3 showed negative for days to tassel, days to ear and positive for plant height and seed weight per plant. On another hand, inbred #1 exhibited negative for days to tassel, days to ear, plant height traits and positive for seed weight per plant. Since the plant height of hybrid adapted to multiple cropping with soybean need not too high, therefore inbred #1 is a good combiner for early maturity and yield component for tester in developing hybrid for multiple cropping.

The SCA values of selected hybrids for the studied traits were presented in Table 3. There were 42 hybrids selected based on days to tassel, 42 hybrids were selected based on days to ear, 29 hybrids were selected based on plant height, 56 hybrids were selected based on seed weight per plant and 43 hybrids were selected based on yield per plot. Among them, 5 hybrids were selected for all traits. These hybrids were code 10, 29, 40, 56 and #85. These hybrids performed early maturity, short plant and high yield component. Hybrids showed high performance for yield and early maturity would be potentially useful in maize breeding programs to obtain high-yielding hybrids for intercropping in the same climate of West Java, Indonesia.

Evaluation of maize hybrid performance in maize-soybean intercropping:

Table 4 showed means of seed weight per plant from selected maize hybrids planted in different cropping system. The results from this study showed that sole cropping yielded higher than all the maize-soybean intercrop. However, there were 12 maize hybrids possessing higher ear weight per plant than commercial hybrids. Those hybrids were code 7, 24, 27, 28, 39, 61, 75, 78, 84, 95, 99 and #100.

Land Equivalent Ratio (LER) for maize hybrids was also shown in Table 4. There were 31 hybrids possessed LER more than 1 in intercropping maize-soybean intercropping. Similar result also reported by Muraya *et al.*²⁹ explaining that maize/bean intercropping had high economic advantage. He studied that Everton synthetic maize showing higher LER than check varieties KTS and H 614. He explained the characteristic maize for intercropping including modification of canopy geometry and photosynthetic apparatus aside of yield and its components.

Maize hybrid adapted for intercropping with soybean should be selected based on its land productivity as shown by its LER. Li *et al.*³⁰ explained that the LER more than one indicating the high economic advantage of particular intercropping. This intercropping index indicated that intercropping was more advantageous than sole cropping in terms of the efficiency of using environmental resources for growth or by increased plant density. Furthermore, Willey and Reddy³¹ explained that yield advantages in intercropping occurs due to differences in their use of resources and its stability greater than in sole cropping system. Evans and

Wardlaw³² reported that shading and reduced assimilate production have least effect on yield in intercropping, while competition prevails during vegetative periods.

Competitive ratio of maize hybrids cultivated in maize-soybean intercropping system: The competition between maize and soybean in intercropping was predicted by Competitive Ratio (CR) index and is presented in Table 4. The result showed that CR maize-soybean (CRm) was higher than CR soybean/maize (CRs). This indicated that maize hybrids have higher competitiveness than soybean and this is the reason why maize hybrid is stable under multiple cropping. The CRm was greater than 1.00 but CRs was less than 1.00 suggesting that soybean is a mild competitor and it is suitable crop in maize intercropping. Ghosh *et al.*³³ justified that there is a positive advantage when competitive ratio was less than one and the crop can be grown in intercropping, but there was negative benefit when greater than one. Willey and Rao³⁴ showed that CR index measures competitive ability of the crops. It had also an advantageous index over relative crowding coefficient and aggressivity.

An exception occurred in intercropping, in which 31 hybrids showing CRm lower than CRs. Hybrid #74 exhibited highest CRs value. An increase of soybean yield higher compared to maize hybrids yield in this pattern was the important factor to explain why CRs was higher than CRm. This result suggested that these hybrids could be developed as suitable hybrid in maize/soybean intercropping system.

Tolerance of soybean against maize hybrids cultivating in

intercropping: Stress Tolerance Index (STI) predicted the tolerance of soybean in intercropping with maize. The STI used to identify high-yielding genotypes in both stress and non-stress conditions²⁸. He categorized particular crop to be tolerance if STI value is high in which the mean performance of particular crop under stress condition would perform high or similar to one in optimal condition. In this research, STI of soybean was estimated based weight pods, since its growth is under stress in intercropping with maize as indicated by its low CRc value.

The STI value of soybean in intercropping with 105 maize hybrids under maize-soybean intercropping was presented in Table 4. There were 44 hybrids that show high STI. Those hybrids were selected since it gives less stress to soybean to yield higher than other non- selected hybrids. Stress due to cropping system reduced significantly the yield of soybean and difference of STI suggests the genetic variability in maize hybrids for cultivating in intercropping with soybean.

Overall, 11 hybrids were selected that were adopted to cultivate under maize/soybean multiple cropping based on LER, CRm, CRs and STI and performing higher seed weight per plant than commercial hybrids (Table 5). Those hybrids were 24, 26, 40, 56, 61, 62, 75, 78, 81, 90 and #100. These hybrids were suggested to be evaluated their stability and adaptability under maize/soybean multiple cropping for different location and seasons.

Table 4: Means of seed weight per plant, Land Equivalent Ratio (LER), Competitive Ratio (CR) and Stress Tolerance Index (STI) of selected maize hybrids

Hybrids	Code	Mean	LER	CRm	CRs	STI
DR 10×MDR 3.1.4	6	190.34S	1.15	0.87	1.15	0.41 ^d
DR 10×G 20133077	9	150.59	1.03	0.97	1.03	0.46 ^c
DR 10×MDR 1.1.3	12	160.78	1.32	0.76	1.32	0.72 ^a
MDR 9.1.3×DR 18	16	167.22	1.92	0.52	1.92	0.63 ^a
MDR 9.1.3×MDR 7.1.9	24	215.79SSSS	1.38	0.73	1.38	0.60 ^b
MDR 9.1.3×MDR 18.5.1	26	185.42	1.11	0.9	1.11	0.49 ^b
DR 18×MDR 14.2.2	40	166.89	1.85	0.54	1.85	0.59 ^b
MDR 14.2.2×MDR 18.8.1	56	208.88SSS	1.84	0.54	1.84	0.57 ^b
DR 8×M7DR 3.1.4	61	234.6SSSS	1.18	0.85	1.18	0.46 ^c
DR 8×M7DR 4.8.8	62	195.3SS	1.15	0.87	1.15	0.43 ^c
MDR 3.1.4×G 673	71	104.55	1.04	0.96	1.04	0.49 ^b
MDR 3.1.4×MDR 7.1.9	74	173.65	2.34	0.43	2.34	0.46 ^c
MDR 3.1.4×MDR 1.1.3	75	233.85SSSS	1.63	0.61	1.63	0.57 ^b
MDR 4.8.8×G 673	78	225.04SSSS	1.33	0.75	1.33	0.63 ^a
MDR 4.8.8×MDR 7.1.9	81	199.98SS	1.55	0.65	1.55	0.67 ^a
G 673×G 203-1	90	189.84S	1.22	0.82	1.22	0.48 ^b
MDR 7.1.9×MDR 1.1.3	100	217.15SSSS	1.04	0.96	1.04	0.57 ^b

S: Hybrid better than commercial check hybrid Pertiwi-3 based on LSI at 5%, SS hybrid better than Pertiwi and Bisi 2 based on LSI at 5%, SSS hybrid better than Pertiwi-3, Bisi 2 and Bisi 816, SSSS hybrid better than all commercial check hybrid based on LSI 5%, CRm: CR value of maize, CRs: CR value of soybean

Table 5: Selected hybrids based on LER, CRm, CRs, STI and Seed weight/ plant (g)

Hybrids	Code	LER	CRm	CRs	STI	Seed weight /plant (g)
MDR 9.1.3×MDR 7.1.9	24	1.38	0.73	1.38	0.60	215.79
MDR 9.1.3×MDR 18.5.1	26	1.11	0.90	1.11	0.49	185.42
DR 18×MDR 14.2.2	40	1.85	0.54	1.85	0.59	166.89
MDR 14.2.2×MDR 18.8.1	56	1.84	0.54	1.84	0.57	208.88
DR 8×M7DR 3.1.4	61	1.18	0.85	1.18	0.46	234.60
DR 8×M7DR 4.8.8	62	1.15	0.87	1.15	0.43	195.30
MDR 3.1.4×MDR 1.1.3	75	1.63	0.61	1.63	0.57	233.85
MDR 4.8.8×G 673	78	1.33	0.75	1.33	0.63	225.04
MDR 4.8.8×MDR 7.1.9	81	1.55	0.65	1.55	0.67	199.98
G 673×G 203-1	90	1.22	0.82	1.22	0.48	189.84
MDR 7.1.9×MDR 1.1.3	100	1.04	0.96	1.04	0.57	217.15

CONCLUSION

GCA value varies for all inbred lines regarding different testers. Inbreds 1 and #3 are the good combiner for early maturity and yield component for tester in developing hybrid for multiple cropping. Five hybrids were selected based on SCA for early maturity (days to tassel and days to ear), plant height and seed weight per plant. These hybrids were namely hybrids 10, 29, 40, 56 and #85.

There were 11 maize hybrids possessing higher seed weight per plant than commercial hybrids and adapted under maize/soybean multiple cropping based on LER, CRm, CRs and STI. Those hybrids were hybrids 24, 26, 40, 56, 61, 62, 75, 78, 81, 90 and #100.

SIGNIFICANCE STATEMENT

This study finds the combining ability of Indonesian maize inbred line that can be advantageous for maize hybrid under intercropping program in Indonesia. This study will help researchers to discover the genetic of tropical maize under intercropping with soybean that many researchers were not able to explore. Thus a new approach on breeding of maize for intercropping with soybean under tropical condition may be arrived at.

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