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Effect of Integrated crop management and blackgram (*Vigna mungo*) intercropping in maize (*Zea mays*)

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ABSTRACT

A 2 year field experiment was conducted during rainy (*kharif)* seasons of 2019 and 2020 to investigate the influence of integrated crop management (ICM) modules and blackgram (*Vigna mungo* L.) intercropping on crop growth, productivity and crop efficiencies in maize (*Zea mays* L.). The maize crop under ICM_7 [zero-tillage (ZT) + permanent raised-beds (PRB) + crop residue retention (3 t/ha) + 100% RDF + glyphosate pre-planting (PP) followed by (*fb*) pendimethalin pre-emergence (PE) *fb* tembotrione post-emergence (POE) application + 3 irrigations + need-based integrated crop protection] module intercropped with blackgram showed significantly higher plant height, dry matter accumulation (174.2 g/plant), crop growth rate (20.8 g/m^2/day), relative growth rate (115 mg/g/day), average grain (6.17 t/ha), and stover yield (8.2 t/ha) and average crop efficiencies like production (60.2 kg/ha/day), monetary-efficiency (795.5 ₹/ha/day) and irrigation water productivity (4 kg/m^3) over conventional-till and organic module in both study years. Overall, conservation agriculture (CA)-based module involving zero-tillage on PRB, crop residue retention, 100% RDF, glyphosate-PP, pendimethalin-PE and tembotrione-POE with 3-irrigations and other need-based plant protection measures with blackgram intercropping improved growth, yield and crop efficiencies of maize under maize + blackgram-wheat cropping system.

Keywords: Blackgram intercropping, Conservation agriculture, Integrated crop management, Maize growth indices

Globally, maize (*Zea mays* L.) commands the first position in food grain production with an average productivity of 5.82 t/ha. In India, maize occupies the third position in food grain production next to rice and wheat with 28.6 million tonnes production with average productivity of 2.94 t/ha. Although rice–wheat cropping system (RWCS) holds key to the food security of the country, there are several production-and resource-constraints associated with this system; the prominent ones being land and water resource deterioration due to intensive cropping, yield stagnation, water table decline, groundwater pollution, higher energy and production costs, declining soil organic matter, multi-nutrient deficiencies, herbicide resistance, low resources-use efficiency and complex incidences of pests/diseases along with climate change vulnerabilities (Bhatt *et al*. 2016, Dass *et al*. 2017).

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To address these issues replacing rice with maize and other crops like cotton, legumes in non-traditional rice areas, especially in upper and trans-indo-gangetic plains where groundwater depletion is a serious concern, could be one of the strategies. And to sustain the maize cultivation, its productivity and profitability needs to be enhanced while simultaneously maintaining or improving environmental and soil conditions. Crop productivity cannot be increased by emphasizing on individual production factors, rather all major factors of production are required to be integrated and considered in their entirety. Information on integrated crop management (ICM) in crops in general and cereal+legume intercropping in particular is lacking. Thus, the current investigation aimed at developing ICM modules for maize+blackgram intercropping. ICM combines appropriate agronomic management practices in an integrated manner for raising a good crop (Choudhary *et al*. 2020). It is an alternative crop production system that conserves natural resources while maintaining economic, social and environmental sustainability in crop production. Maize+legume intercropping is more important in increasing food grain production besides nutritional security, resource conservation, reducing crop failure risk, soil health enhancement and soil conservation, etc. Hence, crop production practices are to be redefined under integrated crop management modules for better productivity and profitability.

MATERIALS AND METHODS

A two-year field experiment was conducted during rainy (*kharif*) seasons of 2019 and 2020 at the research farm of ICAR–Indian Agricultural Research Institute, New Delhi (latitude 28º63' N and longitude 77º15' E) on maize+blackgram-wheat cropping system. The experimental field has Typic Ustocrept alluvial soil with sandy loam texture. The study area receives mean annual precipitation of 875 mm. Soil analysis (0–15 cm) carried out at the initiation of the current experiment using standard procedures (Rana *et al*. 2014) revealed soil *p*H 8.23, soil organic carbon 0.48%, available N 194.1 kg/ha, available P 14.8 kg/ha, available K 303.4 kg/ha. The field experiment was conducted in a three-time replicated split-plot design with nine main-plot treatments (ICM modules, viz. ICM_1 to ICM_4-conventional tillage (CT)-based; ICM_5 to ICM_8-conservation agriculture (CA)-based; ICM_9-organic system) (Table 1) and two cropping systems in sub-plots, viz. maize-wheat, maize+blackgram-wheat. Under maize+blackgram intercropped plots, hand weeding and its mulching was followed instead of herbicides. The crop residues from preceding wheat crop were used for mulching in CA-based plots. Each irrigation of 45 and 60 mm depth was applied to flat bed and raised bed-based ICM modules, respectively. For integrated nutrient management (INM), the crop was supplied with urea, single super phosphate and muriate of potash along with NPK-biofertilizer (NPK-bf) and arbuscular mycorrhizal fungi (AMF) in both CT and CA-based treatments. Under the organic module (ICM_9), FYM, NPK-bf and AMF were used to supply nutrients (Table 1).

Double-discing followed by harrowing was done as a part of seedbed preparation. In CA-based no-till plots, pre-planting application of glyphosate 15 days prior to sowing was done. Maize cultivar PMH-1 was sown using seed rate of 20 kg/ha at 70 cm × 20 cm spacing on 15^{th} and 13^{th} of July and harvested on the 25^{th} and 22^{nd} of October during *kharif* 2019 and 2020, respectively. Additive series intercropping with 100% population of the base crop (maize) was adopted in maize + blackgram plots. Blackgram cultivar Pant U 30 at 10 kg/ha was sown in between maize rows and harvested three weeks earlier than maize. The whole dose of P and K were applied as basal, while N was applied in three equal splits i.e. basal, knee-high and tasselling stage, respectively.

Plant growth attributes, like height, and dry matter accumulation were recorded at 30-day interval. Growth indices like crop growth rate (g/m^2 ground area/day) and relative growth rate (mg/g dry matter/day) were calculated using standard procedures (Rana *et al*. 2014). After harvesting, the grains were sun-dried (till 14% seed moisture), threshed, and cleaned; then the maize grain, stover yield, harvest index and production, monetary-efficiency and irrigation water productivity were computed and the statistical analyses was performed as per the standard procedure suggested (Rana *et al*. 2014). Statistical analyses ($P<0.05$) were performed to determine significant differences

Table 1 Details of nine ICM modules (main-plot) followed in maize (M)/maize+blackgram (M+B) crop

ICM module	Component of ICM module
ICM1	Conventional tillage (CT) + Flat-beds (FB) + 100% of recommended dose of fertilizers-RDF @150:80:60 kg $N:P_2O_5:K_2O$/ha (RDF) + {Pendimethalin as pre-emergence (PE) @1 kg a.i./ha followed by (*fb*) Tembotrione @110 g/ha as post-emergence (POE) at 25 DAS (M)/Pendi-PE @1 kg a.i./ha + 1 hand-weeding and its mulching at 25 DAS (1 HW-mulch) (M+B)} + 3 irrigations (60 mm each) + Need based IDM/IPM
ICM2	CT–FB + 75% RDF @112.5:60:45 kg $N:P_2O_5:K_2O$/ha + Arbuscular Mycorrhizal fungi (AMF) @12.5 kg/ha + NPK-biofertilizer formulation (NPK-bf) @125 ml/ha + {Pendi-PE *fb* Tembo-POE (M)/Pendi–PE + 1HW-mulch (M+B)} + 3 irrigations (60 mm each) + Need based IDM/IPM
ICM3	Conventional tillage (CT) + Raised-beds (RB) + 100% RDF + {Pendi-PE *fb* Tembo-POE (M)/Pendi–PE + 1HW-mulch (M+B)} + 3 irrigations (45 mm each) + Need based IDM/IPM
ICM4	CT–RB + 75% RDF+AMF+NPK-bf + {Pendi-PE *fb* Tembo-POE (M)/Pendi–PE + 1HW-mulch (M+B)} + 3 irrigations (45 mm each) + Need based IDM/IPM
ICM5	Zero-tillage (ZT) + Flat-beds (FB) + {wheat crop residues retention (CRR) @3 t/ha + {100% RDF} + {Glyphosate pre-planting (PP) @1 kg a.i./ha 15 days prior to sowing *fb* Pendi-PE *fb* Tembo-POE (M)/Glypho-PP *fb* Pendi–PE + 1HW-mulch (M+B)} + 3 irrigations (60 mm each) + Need based IDM/IPM
ICM6	ZT–FB + CRR @3 t/ha + 75% RDF+AMF+NPK-bf + {Glypho-PP *fb* Pendi-PE *fb* Tembo-POE (M)/Glypho-PP *fb* Pendi–PE + 1HW-mulch (M+B)} + 3 irrigations (60 mm each) + Need based IDM/IPM
ICM7	Zero-tillage (ZT) + Permanent raised-beds (PRB) + CRR @3 t/ha + 100% RDF + {Glypho-PP *fb* Pendi-PE *fb* Tembo-POE (M)/Glypho-PP *fb* Pendi–PE + 1HW-mulch (M+B)} + 3 irrigations (45 mm each) + Need based IDM/IPM
ICM8	ZT–PRB + CRR @3 t/ha + 75% RDF+AMF +NPK-bf + {Glypho-PP *fb* Pendi-PE *fb* Tembo-POE (M)/Glypho-PP *fb* Pendi–PE + 1HW-mulch (M+B)} + 3 irrigations (45 mm each) + Need based IDM/IPM
ICM9	CT–FB + CRR @3 t/ha + FYM @15 t/ha+AMF+NPK-bf + {1 HW-mulch at 25 DAS} + 3 irrigations (60 mm each) + Need based organic IDM/IPM

*IDM, Integrated disease management; IPM, Integrated pest management.

among treatment means using SAS (v 9.1) software.

RESULTS AND DISCUSSION

Plant growth parameters: ICM modules have a significant effect on plant height. Among the ICM modules ICM_7 [ZT–PRB + CRR at 3 t/ha + 100% RDF + glyphosate-PP *fb* pendimethalin-PE *fb* tembotrione-POE application + 3 irrigations + need-based integrated crop protection] resulted in significantly taller plants at 30, 60 and 90 DAS and ICM_9 recorded the least plant height (Table 2). Dry matter accumulation (DMA) was slow during the initial stages, but increased dramatically between 60 and 90 DAS. DMA of the CA-based ICM_7 module was significantly higher than CT modules. The trend in DMA was ICM_7>ICM_8>ICM_5>ICM_3>ICM_6>ICM_4>ICM_1>ICM_2> ICM_9 in both study years (Table 2). Among cropping system (CS), the maize + blackgram-wheat cropping system (MBWCS) resulted in significantly taller plants with high DMA over maize-wheat cropping system (MWCS).

Plant growth indices: ICM modules significantly influenced the crop growth rate (CGR) of maize till 90 DAS; with increasing maturity, CGR increased (till 90 DAS), then decreased till harvest (Table 2). Highest CGR was observed at 60–90 DAS in ICM_7 under CA and ICM_3 under CT modules. CGR was highest under MBWCS. Over the entire crop duration, relative growth rate (RGR) was in declining trend. In comparison to other ICM modules, the CA-based ICM_7 module showed significantly higher RGR at 30–60 and 60–90 DAS on both years of the experiment (Table 2). Generally, ICM_7 module under CA and ICM_3 module under CT showed superior plant growth and growth indices in no-till and conventional-till crop establishment techniques, respectively. Organic input based ICM_9 module exhibited the lowest plant growth and DMA, which ultimately led to a low maize productivity. CA-based modules had highest plant growth rate over CT and organic module. In general, CA-based modules had significantly higher CGR and RGR values at 30–60 and 60–90 DAS than CT-based ICM modules. Among CS, MBWCS resulted in significantly higher growth indices than MWCS. Among the crop establishment methods, the RB/PRB planting performed significantly better than flatbeds in both CT and CA-based modules (Choudhary *et al*. 2020). According to Harish *et al*. (2021), maize crop established on RB/PRB recorded enhanced plant growth, DMA as well as crop growth indices like CGR, RGR and NAR, which resulted in 13.1% higher maize grain yield in RB/PRB than CT-FB (Harish *et al*. 2022). The 75% RDF+NPK-bf+AMF supplied modules were at par with 100% RDF applied ICM modules in both CA and CT (Choudhary *et al*. 2020). Similarly, under RWCS, application of 100% RDF stood at par with 75% RDF+AMF+NPK-bf in terms of plant growth and productivity due to positive benefits from dual inoculation of AMF and NPK-bf. Similar, nutrient substitution results were reported in other crops like soybean (Rohullah 2016) and pigeonpea (Varatharajan *et al*. 2019). CA-based ICM_7 module had significantly higher growth parameters like plant height, DMA and growth indices because of minimal heat- and moisture-stress under residue retention over bare CT based ICM modules (Choudhary *et al*. 2020). The combined effect of fertilizer application, nutrient release from the decomposition of crop residues retained and blackgram intercropping altogether increases nutrient availability in CA-based treatments that led to superior plant root and shoot growth which, in turn increases growth indices like CGR and RGR (Singh *et al*. 2020). Organic acids released during the decomposition of crop residues retained further help in solubilization and uptake of insoluble macro- and micro-nutrients from the soil. Interaction between residue retention, microbial inputs and blackgram intercropping helps the ICM modules with 75% RDF+NPK-bf+AMF to perform at par with 100% RDF applied modules (Choudhary *et al*. 2020).

Maize productivity: CA-based ICM_7 module produced significantly higher grain (6.13, 6.20 t/ha) and stover (8.15, 8.25 t/ha) yields over CT and organic module in both years of experiment. Both grain and stover yields under CA were higher than CT and organic module and followed the trend ICM_7>ICM_8>ICM_5>ICM_6>ICM_3>ICM_4>ICM_1>ICM_2> ICM_9. Even though ICM modules had no effect on harvest-index (HI), CT has high HI than CA-based modules (Fig 1a). CA-PRB had ~3% more grain yield than CA-FB; and CT-RB had ~6% more grain yield than CA-FB. Moreover, CA practices improved maize grain yield by ~9% over CT. Under CS, MBWCS had significantly higher grain (5.68; 5.82 t/ha) and stover (7.41; 7.58 t/ha) yields during both years of experiment except harvest index (Fig 1b).

The interaction effect between ICM modules and cropping system on grain and stover yields were significant and was in similar trend as discussed above. Maize+blackgram intercropping produced 5% higher yield than sole maize (Upasani *et al*. 2000). Combined application of NPK-bf and AMF could lead to improved N fixation, P and K solubilization/mobilization, which enhances crop yield due to high available N, P and K (Kumar *et al*. 2015).

In general, CA-based ICM modules were superior to CT, due to better nutrient and moisture availability, less water stagnation on heavy downpour, conducive microclimate for soil biological activity (Singh *et al*. 2020), better root growth from less machine traffic and improved available nutrients. In addition, better root growth and moisture availability under CA practices improved maize grain yield over CT practices. Microbial decomposition of surface retained residue as well as improved nutrient acquisition could improve grain yield under CA (Singh *et al*. 2020). AMF application improves root growth and foraging area of root hairs for better nutrient uptake from soil (Kumar *et al*. 2015). Further, biomolecules released from microbial biofertilizers and AMF help in solubilizing, mobilizing and acquisition of fixed nutrients from the soil for better yields under 75% RDF (Singh *et al*. 2020).

Under both CT and CA, raised-bed planting significantly improved grain and stover yields due to better canopy growth and development, enhanced photosynthetically

Table 2 Effect of ICM modules and cropping systems on plant height, DMA, CGR and RGR at 30-day interval in maize

Treatment	Plant height (cm)						DMA (g/plant)						CGR (g/m^2/day)				RGR (mg/g/day)			
	30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS		30–60 DAS		60–90 DAS		30–60 DAS		60–90 DAS	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Integrated crop management module																				
ICM_1	64.0	65.3	171.0	173.8	225.5	230.6	25.7	26.7	74.6	76.8	157.7	159.3	11.6	11.9	19.8	19.6	35.5	35.2	25.0	24.3
ICM_2	63.0	63.0	168.8	169.6	225.4	226.9	24.8	25.4	75.1	76.9	156.3	160.0	12.0	12.3	19.3	19.8	36.9	37.0	24.4	24.4
ICM_3	69.3	70.6	174.0	179.4	240.1	241.2	26.4	28.3	78.5	79.7	164.5	165.4	12.4	12.3	20.5	20.4	36.3	34.6	24.7	24.3
ICM_4	67.9	69.0	171.2	177.0	233.1	236.2	26.0	27.1	77.6	78.5	161.0	161.6	12.3	12.2	19.9	19.8	36.4	35.5	24.4	24.1
ICM_5	72.4	73.5	177.6	181.3	239.4	244.4	28.9	29.8	82.3	83.0	166.2	167.4	12.7	12.7	20.0	20.1	35.0	34.2	23.4	23.4
ICM_6	67.6	68.8	179.2	180.3	239.0	242.9	26.8	27.7	81.0	83.2	163.0	164.9	12.9	13.2	19.5	19.5	36.9	36.7	23.3	22.8
ICM_7	74.7	75.2	185.7	187.1	241.8	244.8	32.2	32.3	86.6	87.0	174.3	174.0	13.0	13.0	20.9	20.7	33.1	33.1	23.3	23.1
ICM_8	73.0	73.7	180.6	182.6	237.7	240.1	30.7	31.5	85.4	86.2	166.2	168.6	13.0	13.0	19.2	19.6	34.1	33.6	22.2	22.4
ICM_9	58.5	60.5	168.3	160.1	222.6	223.8	24.2	24.8	70.5	73.2	152.3	146.8	11.0	11.5	19.5	17.5	35.7	36.1	25.7	23.2
SEm±	1.1	1.2	2.0	2.4	2.6	3.1	0.7	0.6	1.2	1.4	1.5	2.0	0.4	0.3	0.3	0.5	1.1	0.8	0.5	0.7
CD (P=0.05)	3.2	3.7	5.9	7.2	7.8	9.4	2.1	1.9	3.5	4.3	4.4	6.0	1.1	1.0	1.0	1.6	NS	2.4	1.4	NS
Cropping systems																				
M–W	66.2	66.1	171.8	172.9	231.2	233.4	26.2	27.0	77.3	78.8	159.0	159.9	12.2	12.3	19.5	19.3	36.1	35.8	24.1	23.6
M+B–W	69.5	71.6	178.5	180.8	236.5	240.1	28.4	29.3	80.8	82.2	165.7	166.3	12.5	12.6	20.2	20.0	35.0	34.4	24.0	23.5
SEm±	0.4	0.4	0.8	0.7	1.2	1.8	0.1	0.1	0.4	0.2	0.6	0.6	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
CD (P=0.05)	1.2	1.1	2.5	2.0	3.6	5.3	0.4	0.3	1.3	0.7	1.8	1.7	0.3	0.2	0.5	0.4	0.6	0.5	NS	NS

M-W, Maize-wheat; M+B-W, Maize+blackgram-wheat

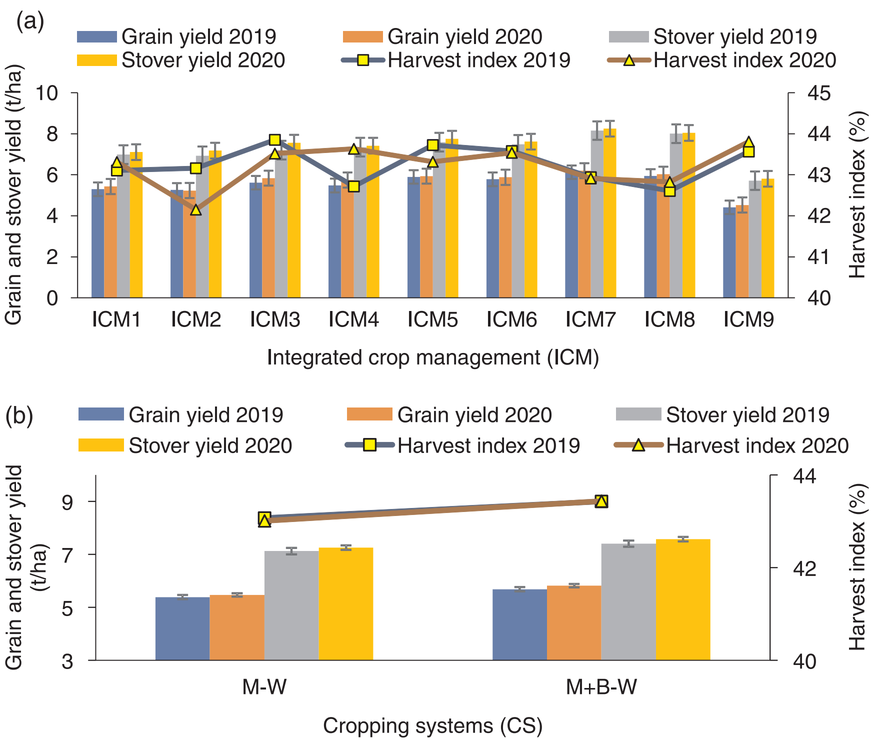

Fig 1 Effect of ICM modules (a) and cropping systems; (b) on grain, stover yields and harvest index of maize

active radiation interception (PAR$_i$), improved resource- and water-use efficiency, low waterlogging stress in early and terminal growth stages, optimal soil physical environment and less weed competition. Blackgram intercropping significantly enhances PAR$_i$ and resource-use efficiency in maize (Kermah *et al*. 2017, Liu *et al*. 2017) and the blackgram intercrop component under MBWCS, reduces weed density by smothering, improves nutrient recycling from leaf fall and support cereal crop through legume effect and atmospheric nitrogen fixation which positively augments the yield of the maize (Manasa *et al*. 2018, Abbas *et al*. 2021).

Production-, monetary-efficiency and irrigation water productivity: Under CA-based ICM$_7$ module, maize production- and monetary-efficiency was significantly higher as higher dry matter accumulation resulted in higher yield and monetary return. Both ICM modules and cropping system affect irrigation water productivity (IWP) of maize in a significant way. Under CA, ICM$_7$ module had significantly higher IWP (4.54; 3.45 kg/m^3); while under CT, ICM$_3$ module recorded greater IWP (4.16; 3.24 kg/m^3) during both the years, respectively. MBWCS had highest IWP (3.65; 2.81 kg/m^3) (Table 3).

The raised bed-based crop establishment with less amount of water application (45 mm) led to higher root growth and other root parameters, which ultimately increases the exploratory area of root in soil that in turn

Table 3 Effect of ICM modules and cropping systems on production, monetary-efficiency and IWP of maize

Treatment	Production-efficiency (kg/ha/day)		Monetary-efficiency (₹/ha/day)		Irrigation-water productivity (kg/m^3)	
	2019	2020	2019	2020	2019	2020
Integrated crop management module						
ICM$_1$	51.4	53.2	640.9	696.6	2.94	2.26
ICM$_2$	51.1	51.3	660.8	689.3	2.93	2.18
ICM$_3$	54.6	57.2	707.0	789.4	4.16	3.24
ICM$_4$	53.2	56.3	713.6	795.4	4.06	3.19
ICM$_5$	57.3	58.2	707.8	753.2	3.28	2.47
ICM$_6$	56.1	57.6	711.5	765.8	3.21	2.45
ICM$_7$	59.5	60.8	768.4	822.4	4.54	3.45
ICM$_8$	57.7	59.1	758.7	811.2	4.40	3.35
ICM$_9$	42.8	44.4	383.6	423.8	2.45	1.89
SEm±	1.1	1.2	22.4	25.0	0.07	0.06
CD (P=0.05)	3.2	3.6	67.3	74.9	0.21	0.17
Cropping system						
M–W	52.3	53.6	671.6	718.8	3.46	2.63
M+B–W	55.2	57.1	673.4	736.0	3.65	2.81
SEm±	0.3	0.2	4.8	4.1	0.02	0.01
CD (P=0.05)	0.8	0.6	NS	12.1	0.05	0.03

M-W, Maize-wheat; M+B-W, Maize+blackgram-wheat helps in better water and nutrient uptake from deeper soil layers. This helps in improving grain yield and IWP of RB/PRB-based CA and CT modules (Halli *et al*. 2021). Synergistic cereal-legume below ground root interaction which upregulates the carbon metabolism of both crops contributes in improving grain yield and IWP of MBWCS (Jiao *et al*. 2021). Maize+blackgram under MBWCS enhances maize equivalent yield, land equivalent ratio and relative net return (Kheroar and Patra 2014). In total, the CA-based ICM practices with blackgram intercrop could increase the stability of crop yields and soil health under climatic stress.

Overall, the 2-year study demonstrated that CA-based ICM_7 module with ZT + PRB + CRR @3 t/ha + 100% RDF + Glyphosate-PP *fb* Pendimethalin-PE *fb* Tembotrione-POE + 3 irrigations + need based IDM/IPM with blackgram intercropping is beneficial in improving growth, yield and crop efficiencies of maize under MBWCS.

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