Tanyi *et al. Chem. Biol. Technol. Agric.* (2018) 5:25
https://doi.org/10.1186/s40538-018-0140-1

Chemical and Biological Technologies in Agriculture

RESEARCH

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Effects of climate variability on insect pests of cabbage: adapting alternative planting dates and cropping pattern as control measures

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Abstract

Background: Considering the potential impact of climate change on the ecology of insect pests, different planting dates and cropping patterns were investigated as farm-level adaption to control insect pests of cabbage and improve productivity.

Methods: This is a 3 × 4 factorial experiment setup in randomized complete block design including three planting dates (early, normal and late) and four cropping patterns (control—sole cabbage or tomato, tomato intercrop, *Piper* emulsion and insecticide) with four replications each.

Results: Cabbage infestation ranged from 1 to 29 and correlated negatively with planting dates or treatments, which differed ($P < 0.001$) significantly across planting dates, treatments and their interaction, with the highest during early planting. Diamondback moth larvae correlated negatively with planting dates or treatments, ranging from 0 to 13 that differed significantly ($P < 0.001$) across planting dates, treatments and their interaction. Looper larvae correlated negatively with treatments, ranging from 0 to 8 that differed significantly ($P < 0.001$) across planting dates, treatments and their interaction, with highest during normal planting and lowest during late planting. Webworm larvae correlated negatively with planting dates or treatments, ranging from 0 to 13 that differed significantly ($P < 0.001$) across planting dates, treatments and their interaction. The number of sprouted plants ranged from 0 to 6 and differed significantly ($P < 0.001$) across planting dates, treatments and their interaction, with the highest in early planting for control that differed significantly from late planting. Cabbage yield correlated positively with planting dates and ranged from 2.8 to 6.0 tons per hectare that differed significantly ($P < 0.001$) across planting dates, treatments and their interaction, with the highest during normal and late planting dates.

Conclusion: The interaction of planting dates and *Piper* emulsion or intercropping treatments can be effectively used as control measure for insect pests of cabbage leading to greater yield, with late planting as viable farm-level adaptation to climate variability.

Keywords: Climate change, Diamondback moth, Intercropping, Piper botanical, Planting date

Background

Climate variability poses constraints on agricultural production with significant effects on cropping seasons and food security [1]. Sub-Saharan Africa (SSA) is more vulnerable to climate change due to its reliance on agriculture that is highly sensitive to climate variables, and the low capacity for adaptation [2]. Climate change affects most crops including vegetables that are sensitive to climate shocks [3]. Extreme weather events such as heavy rainfall, droughts and heat waves have increased in recent decades, with significant implications on agricultural productivity [4, 5]. Periodic droughts and changes in rainfall frequency or severity can severely influence the ecology of insect pests in arable fields [6–8]. In view of current global climate change scenarios, there is overdue

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need for sustainable adaptive farm management strategies [9].

Many insect pests hinder cabbage (*Brassica oleracea* L.) cultivation and the most damaging is Diamondback moth—DBM (*Plutella xylostella* L.) (Lepidoptera: Plutellidae) that causes up to 90% yield loss [10]. DBM, Looper *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae) and webworm *Hellula undalis* (Fabricius) (Lepidoptera: Pyralidae) can cause sprouting, contamination with frass, or even kill young plants [11]. Reliance on synthetic insecticides to control crop pests usually leads to environmental pollution, pest resistance and high production costs [12–16]. The prevention, avoidance, monitoring and suppression (PAMS) model was successfully used to evaluate pest management strategies [17]. Prevention involves crop rotation and use of resistant cultivars, while avoidance involves alternative planting dates and intercropping [17, 18]. Tomato intercrop [18–20], botanicals and planting dates [21–24] have demonstrated efficacy and cost-effectiveness as control measures for cabbage pests.

Climate variability was projected to cause varying effects on crops including significant yield decrease in eight agricultural regions across Cameroon [25, 26]. Despite limitations in climate data for the study area, recent meteorological data showed significant weather variations with increased annual temperature from 26 °C in 2010 to 27.2 °C in 2012 and 2014, while annual rainfall decreased from 3135 mm in 2013 to 1993 mm in 2014 [27]. These temperature and rainfall fluctuations can affect farming systems by disrupting the normal planting schedule. Consequently, alternative planting and harvesting dates were suggested as potential farm-level adaptations to climate variability in this study area and across Cameroon [28]. Accordingly, Ngondjeb [29] advocated effective agricultural planning for the impact of climate variability in Cameroon. It is therefore important to consider the effects of climate variability on the ecology of insect pests in arable systems, and potential integrated management approach involving alternative planting dates and cropping patterns. Hence, this study was intended to adapt alternative planting dates and cropping pattern as control measures for cabbage pests under climate change scenarios. It was hypothesized that shifting from normal to late planting dates, and the interaction of planting dates and treatments will lead to significant reduction of insect pests and increased cabbage yield.

Methods

Experimental site and setup

This study was conducted at the research and teaching farm of the Faculty of Agriculture and Veterinary Medicine, University of Buea. The site is located in Molyko Buea, situated between latitudes 4°3′N and 4°12′N and longitudes 9°12′E and 9°20′E. The soil is derived from weathered volcanic rocks dominated by silt, clay and sand [30, 31]. The rainfall regime is mono-modal with less pronounced dry season and 85–90% relative humidity, and the dry season starts from November to March [32]. It has a mean annual rainfall of 2800 mm and monthly air temperature ranging from 19 to 30 °C, while soil temperature at 10 cm depths decreases from 25 to 15 °C with increasing elevation from 200 to 2200 m above sea level, respectively [30, 33, 34]. Mean monthly temperature ranged from 17.3 to 19.7 °C and precipitation from 30 to 429 mm in Buea during the experimental period (Table 1).

This is a 3 × 4 factorial experiment setup in randomized complete block design including three planting dates (early—24th January 2016, normal—10th March 2016 and late—15th April 2016) and four cropping patterns (control—sole cabbage or sole tomato, tomato intercrop, *Piper* emulsion and insecticide) with four replications each. The experimental field was cleared manually using a cutlass and partitioned into 16 plots measuring 3 × 4 m each (12 m^2), and manually tilled at about 30 cm depth using a hoe. The sole cabbage plots contained 8 rows and 6 columns of cabbage plants at 50 × 50 cm inter- and intra-row spacing, leading to 48 plants per plot. Cabbage–tomato intercrop plots contained 4 rows and 3 columns of cabbage and tomato plants each, leading to 48 plants per plot (24 plants per crop). These were planted at 50 × 50 cm inter- and intra-row spacing on one alternate row between cabbage and tomato plants. A non-tilled 50-cm buffer zone separated the experimental plots from each other.

Table 1 Mean monthly temperature and precipitation in Buea during the experimental period

Months	Temperature (°C)	Rainfall (mm)
January	19	30
February	19.4	65
March	19.7	161
April	19.6	188
May	19.1	244
June	18.3	264
July	17.3	429
August	17.4	488
September	17.7	482
October	18.3	323
November	18.8	112
December	18.9	29

Source: https://en.climate-data.org/africa/cameroon/southwest/buea-3985/

Plant cultivation

Hybrid cabbage (F1 Green Coronet; STARKE AYRES®, France; that are heat and cold resistant) and tomato (F1 Cobra 26; TECHNISEM®, France; adapted for Sahelian and tropical areas with tolerance to disease and high productivity) seeds were purchased from an agro-shop in Buea Cameroon. The F1 Green Coronet seeds and F1 Cobra 26 seeds were pre-germinated on separate beds at 15×15 cm inter-row spacing on nearby 2.5×1 m nursery beds that were cleared using cutlasses and tilled manually using hoes, and manually irrigated using a watering can. For all planting dates, vigorous cabbage seedlings of similar sizes were transplanted from the nursery, followed by tomato transplant 2 weeks later. After transplanting, all plots were manually irrigated every 2 days to maintain optimum soil moisture for plant growth and performance.

Both cabbage and tomato nurseries were amended with 0.5 kg inorganic fertilizer NPK 20:10:10 + CaO (ADER® Cameroon), and treated with a mixture of synthetic insecticides and fungicides. 35 mL insecticide (K-Optimal; SCPA SIVEX International® France; comprising 15 g/L lambda − cyhalothrine + 20 g/L acetamiprid active ingredients) and 100 g fungicide (Mancozan super; SCPA SIVEX International® France; comprising 640 g/kg mancozeb + 80 g/kg metalaxyl active ingredients) were dissolved in 15 L water and applied using a knapsack sprayer. After transplanting, all experimental plots were manually irrigated every 2 days to maintain optimum soil moisture for plant growth and performance. Weed emergence was monitored regularly on all experimental plots and weeded manually using a hoe.

Fertilizer amendment

All experimental plots were amended with the same type and amount of soil applied organic and inorganic fertilizers. Organic poultry dropping (obtained from a poultry farm in Molyko Buea) was broadcasted on all experimental plots 7 days before the crops were transplanted. Thirty days after transplanting, inorganic NPK 20:10:10 + CaO (ADER® Cameroon) was applied on all experimental plots at 5 g per plant by ringing at 5 cm from plants.

Insecticides and fungicides

The synthetic plots were sprayed with commercial insecticide (K-Optimal; SCPA SIVEX International® France) and fungicide (Mancozan super; SCPA SIVEX International® France). The cabbage–tomato intercrop plots were not sprayed with *Piper* emulsion or synthetic insecticide and the tomato plants served as repellent or attractant of cabbage pests. Neither *Piper* emulsion nor synthetic insecticide was applied in the sole cabbage or sole tomato control plots.

Piper emulsion botanical

The organic *Piper* emulsion botanical comprised West African black pepper (*Piper guineense*) that was harvested from a primary forest at Inokun-Eyumojock in South-western Cameroon and prepared according to Tanyi et al. [35]. Briefly, 250 g crushed sun-dried *Piper* seed powder was dissolved in 1 L vegetable oil (KING'S®, Lagos-Nigeria) and 10 g detergent (SABA®, Douala-Cameroon) was added to produce a sticky emulsion. The mixture was stirred thoroughly and stored in a plastic container at room temperature while laboratory tests were conducted to determine the effective dose for best field results. 50 mL *Piper* emulsion was filtered using a double 169-folded muslin cloth and diluted in 15 L water for field application every 2 weeks, during cold dry early morning periods with minimal drift. *Piper* emulsion was stirred thoroughly to achieve homogeneity and sprayed using a knapsack sprayer on both sides of cabbage leaves for all 192 plants in the respective plots.

Data collection on cabbage pests

Cabbage plants were assessed for pest infestation before and after heading, while the wrapper leaves were monitored regularly for symptoms of pest damage. Five randomly selected plants were tagged on each plot, and visible signs of damage and occurrence of insect pest larvae were assessed and data presented as number of larvae per plant (mean ± SD). Cabbage plants were identified as infested based on observation of diamondback moth, looper and webworm larvae or their damage, and reported as number of infested plants per treatment (mean ± SD). Diamondback moth (*P. xylostella*) is an important cabbage pest with average development time of 25–30 days from egg to pupal stage depending on weather conditions, and a complete cycle of 17–51 days from egg to adult. The annual number of generations varies from four in cold climates to 12 in warm climates. Diamondback moth was assessed on wrapper leaves and identified as small round holes, scratches or skeleton damage on leaves with partially damaged epidermis that gives cabbage leaves a windowpane appearance. An adult female cabbage Looper (*T. ni*) moth lays from 300 to 600 eggs pale yellow and round eggs in 10–12 days adult lifespan that hatch in 3–10 days, with a more rapid pupal stage in warmer temperatures. The occurrence of webworm larvae and plant damage was identified as leaves held together with silk. Each female cabbage webworm (*H. undalis*) lays about 75–250 eggs singly or in groups of 2–3 on the inner tissues of host plants. The hatching larvae bore into stems of growing points, weaving webs into which they place their frass. Webworm pupates in soil within webbed cocoons that include soil particles as a generation develops in about 4–5 weeks at 27 °C, with short-lived adults and the potential to complete 7–8 generations annually.

Data collection on cabbage yield

Sprouted cabbage plants were assessed and recorded as total number of plants with multiple shoots (sprouts) on each plot and reported as number of sprouted cabbage plants per treatment (mean ± SD). Marketable cabbage heads were harvested manually at physical maturity and the yield presented as weight of harvested cabbage heads per treatment (t ha^{-1}, mean ± SD). At harvesting, ten cabbage plants were incised above the soil on each plot and weighed individually using a top loading balance (Brand MK-01, China). Prior to weighing, a cutter was used to remove all damaged leaves.

Statistical analysis

Datasets were assessed for normality using Kolmogorov–Smirnov and Shapiro–Wilk tests before they were subjected to statistical analyses using STATISTICA 9.1 for Windows [36, 37]. Dependent variables (e.g. cabbage infestation or yield, Diamondback moth, Looper and Webworm) were subjected to multivariate analysis of variance (ANOVA, $P<0.05$) to test the effects of planting dates ($n=3$) and treatments ($n=4$) as categorical predictors. Significant data means were compared by post hoc Tukey's HSD test ($P<0.05$), and Spearman rank correlation ($P<0.05$) was performed to determine the degree of association between dependent variables and categorical predictors.

Results

Cabbage infestation

Cabbage infestation ranged from 1 to 29 and correlated negatively with planting dates and treatments, which differed significantly ($P<0.001$) across planting dates (Fig. 1a), treatments (Fig. 1b) and their interaction. The highest infestation occurred during early planting for the control that differed significantly ($P<0.05$) from the normal and late plantings (Fig. 1a). Differences occurred over time for intercropping treatment as the early planting differed significantly ($P<0.05$) from late planting (Fig. 1a). The highest infestation occurred in control that differed significantly ($P<0.05$; Fig. 1b) from the other treatments. Negative correlations ($P<0.05$) occurred between cabbage infestation and planting dates ($r=-0.48$) or treatments ($r=-0.71$).

Diamondback moth larvae

Diamondback moth-DBM larvae correlated negatively planting dates or treatments, ranging from 0 to 13 that differed significantly ($P<0.001$) across planting dates (Fig. 2a), treatments (Fig. 2b) and their interaction. DBM larvae differed significantly ($P<0.05$; Fig. 2a) across planting dates for control, with highest during early planting and lowest during late planting. Significant ($P<0.05$) treatment effects occurred during the early and normal planting, with the highest DBM larvae recorded in the control that differed from the other treatments (Fig. 2b). Treatment effects on DBM larvae were significant ($P<0.05$) during early planting, with highest in control followed by intercropping, *Piper* emulsion and insecticide (Fig. 2b). Negative correlations ($P<0.05$) occurred between DBM larvae and planting dates ($r=-0.33$) or treatments ($r=-0.69$) with correlations during early ($r=-0.89$) and late ($r=-0.87$) plantings.

Looper larvae

Looper larvae correlated negatively with treatments, ranging from 0 to 8 that differed significantly ($P<0.001$) across planting dates (Table 2A), treatments (Table 2B) and their interaction, with highest for control during normal planting and lowest during late planting ($P<0.05$; Table 2A). Negative correlations ($P<0.05$) occurred between looper larvae and treatments for early ($r=-0.54$), normal ($r^*=-0.62$) and late ($r=-0.51$) plantings.

Webworm larvae

Webworm larvae correlated negatively with planting dates and treatments, ranging from 0 to 13 that differed significantly ($P<0.001$) across planting dates (Table 3A), treatments (Table 3B) and their interaction. Webworm larvae differed significantly ($P<0.05$) for the control, with the lowest in late planting and highest in early planting (Table 3B). Negative correlations ($P<0.05$) occurred between webworm larvae and planting dates ($r=-0.54$) or treatments for early ($r=-0.79$), normal ($r^*=-0.75$) and late ($r=-0.51$) plantings.

Cabbage yield

Sprouted plants ranged from 0 to 6 and differed significantly ($P<0.001$) across planting dates (Table 4A), treatments (Table 4B) and their interaction. The highest number of sprouted plants occurred in early planting for control, which differed significantly ($P<0.05$) from late planting (Table 4A). Negative correlations ($P<0.05$) occurred between sprouted plants and planting dates ($r=-0.4$) or treatments for early ($r=-0.9$), normal ($r^*=-0.8$) and late ($r=-0.5$) plantings. Cabbage yield ranged from 2.8 to 6.0 tons per hectare that correlated ($P<0.05$) positively with planting dates ($r=0.6$), and differed significantly ($P<0.001$) across planting dates (Fig. 3a), treatments (Fig. 3b) and their interaction, with highest during normal and late plantings. The late

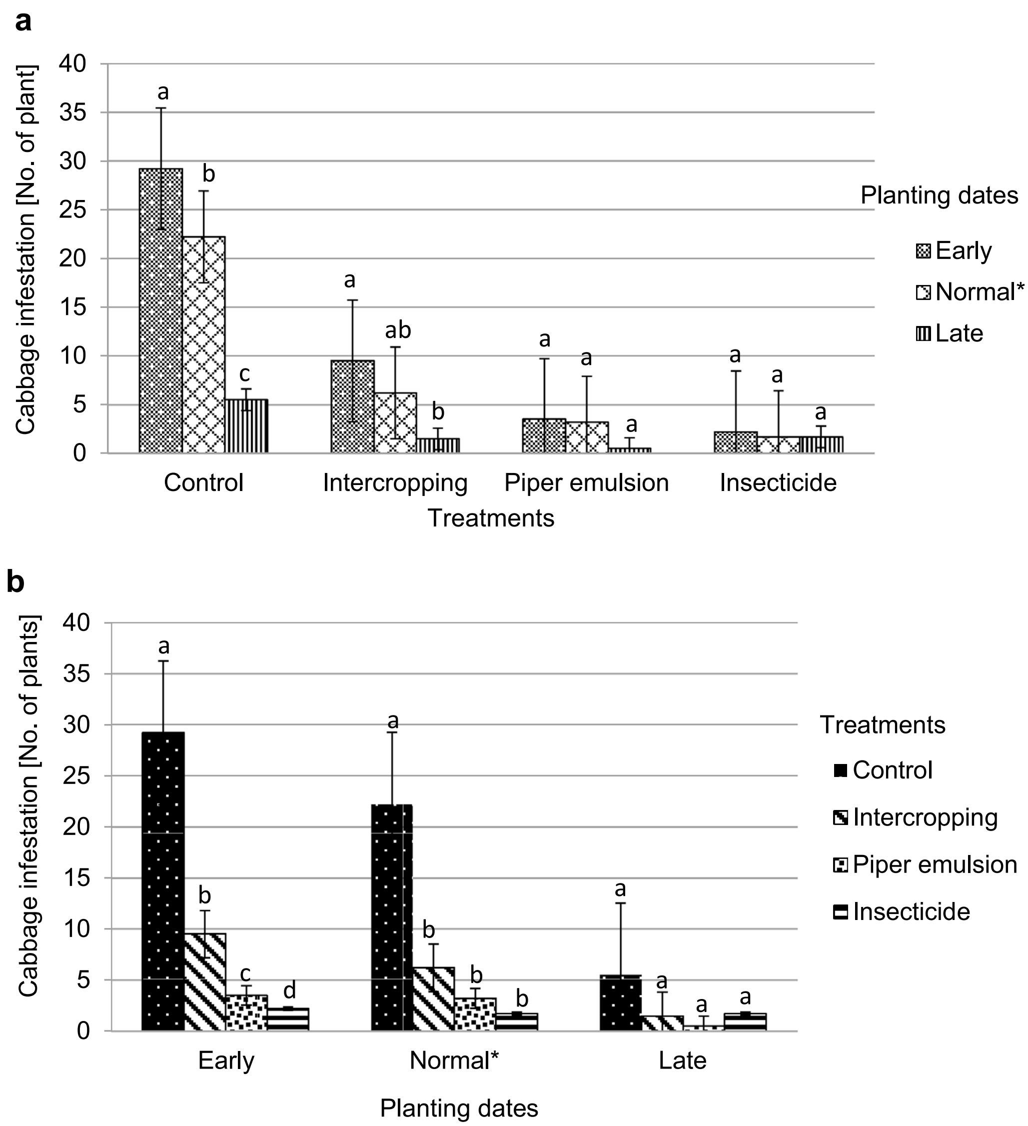

Fig. 1 Effect of planting dates (**a**) (early, normal and late) and treatments (**b**) (control, intercropping, *Piper* emulsion and insecticide) on number of infested cabbage plants (mean ± SD). Values within treatments or planting dates with different letters are significantly different ($P < 0.05$). *Data from Tanyi et al. [35]

planting differed significantly ($P < 0.05$) from early and normal plantings for the control (Fig. 3).

Discussion

Effect of planting dates on cabbage pests

The results of this study are consistent with current trends in climate dynamics, which require adaptation of cropping seasons to the ecology of insect pests, with particular attention on alternative planting dates and sustainable treatments [6, 38]. These results reflect the overdue need for adapted integrated pest management approaches that incorporate planting dates with local farm management practices under different climate scenarios [39]. The significantly low pest infestation during late planting compared to normal and early plantings can be attributed to current climate dynamics in the study area with decreasing rainfall and increasing temperature [27, 38], and demonstrates the efficacy of alternative planting dates as control measure for cabbage pests [28]. The decrease in diamondback moth larvae from early to late plantings is consistent with other results where diamondback moth occurred in vegetable fields during early and normal planting, but disappeared during late planting [40]. Climate variables play important roles in the ecology of insect pests because of their short generations and high reproductive rates

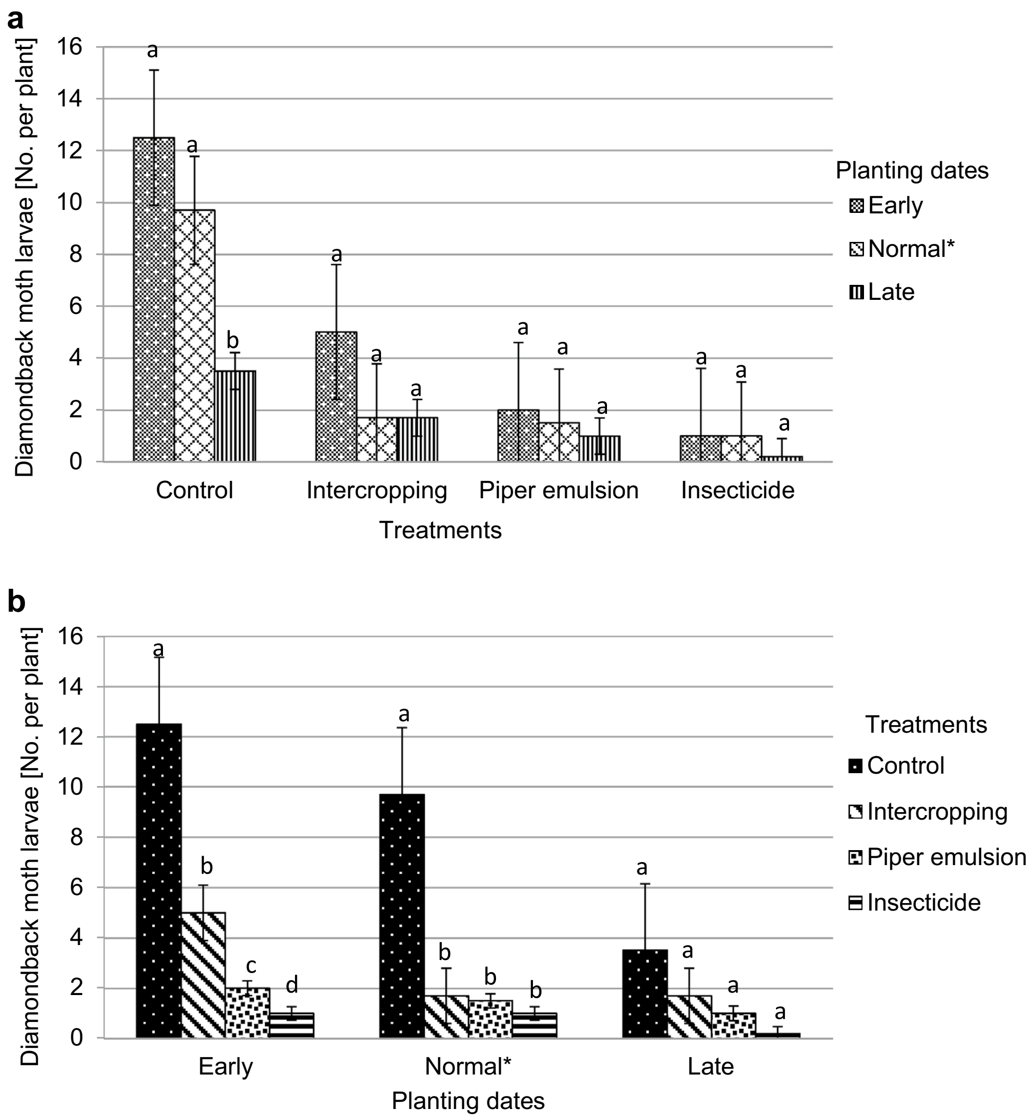

Fig. 2 Effect of planting dates (**a**) (early, normal and late) and treatments (**b**) (control, intercropping, *Piper* emulsion and insecticide) on number of diamondback moth larvae (mean ± SD). Values within treatments or planting dates with different letters are significantly different ($P < 0.05$). *Data from Tanyi et al. [35]

[41, 42], causing significant effects on crop production in Cameroon that require effective planning [29, 43]. In addition, climate variability reduced parasitism of caterpillars leading to variation in the frequency and intensity of herbivory outbreaks [44]. Temperature effects on insect ecology are variable with high temperatures negatively affecting eggs, while low temperatures negatively affect larvae [43, 45]. These results are consistent with the first hypothesis of this study and strongly support a shift to late planting as farm-level adaptation to cabbage pests as compared to the current planting date in the study area.

Besides alternative planting dates, farm management practices demonstrated strong importance as control measure for cabbage pests across the different planting dates. Effectiveness of the evaluated crop protection practices is demonstrated by lack of significant differences in cabbage infestation and pest occurrence between different planting dates for intercropping, *Piper* emulsion and insecticide treatments compared to control [18, 36]. The low insect pest occurrence across treatments during late planting is consistent with the hypothesis of this study, which strongly suggests a shift from the current planting date as farm-level adaptation to climate variability in the study area. This is commensurate with predictions on the

Table 2 Effect of planting dates—A (early, normal and late) and treatments—B (control, intercropping, *Piper* emulsion and insecticide) on number of looper larvae (mean ± SD)

A			
Treatments	**Planting dates**		
	Early	**Normal**[a]	**Late**
Control	6.2 ± 2.0a	8.3 ± 1.7a	0.2 ± 0.5b
Intercropping	0.2 ± 0.5a	0.2 ± 0.5a	0.0 ± 0.0a
Piper emulsion	0.0 ± 0.0a	0.5 ± 0.5a	0.0 ± 0.0a
Insecticide	0.7 ± 0.9a	0.7 ± 0.9a	0.5 ± 0.5a

B				
Planting dates	**Treatments**			
	Control	**Intercropping**	***Piper* emulsion**	**Insecticide**
Early	6.2 ± 2.0a	0.2 ± 0.5a	0.0 ± 0.0a	0.7 ± 0.9a
Normal[a]	8.3 ± 1.7a	0.2 ± 0.5a	0.5 ± 0.5a	0.7 ± 0.9a
Late	0.2 ± 0.5b	0.0 ± 0.0a	0.0 ± 0.0a	0.5 ± 0.5a

Values within rows with different letters are significantly different ($P < 0.05$)

[a] Data taken from Tanyi et al. [35]

Table 3 Effect of planting dates—A (early, normal and late) and treatments—B (control, intercropping, *Piper* emulsion and insecticide) on number of webworm larvae (Mean ± SD)

A			
Treatments	**Planting dates**		
	Early	**Normal**[a]	**Late**
Control	12.5 ± 3.1a	5.5 ± 3.1b	1.5 ± 1.7b
Intercropping	4.5 ± 2.6a	4.2 ± 3.0a	0.2 ± 0.5a
Piper emulsion	1.5 ± 2.3a	1.2 ± 0.9a	0.0 ± 0.0a
Insecticide	1.0 ± 0.8a	0.5 ± 1.0a	0.0 ± 0.0a

B				
Planting dates	**Treatments**			
	Control	**Intercropping**	***Piper* emulsion**	**Insecticide**
Early	12.5 ± 3.1a	4.5 ± 2.6a	1.5 ± 2.3a	1.0 ± 0.8a
Normal[a]	5.5 ± 3.1b	4.2 ± 3.0a	1.2 ± 0.9a	0.5 ± 1.0a
Late	1.5 ± 1.7b	0.2 ± 0.5a	0.0 ± 0.0a	0.0 ± 0.0a

Values within rows with different letters are significantly different ($P < 0.05$)

[a] Data taken from Tanyi et al. [35]

ecology of insect pests under climate change scenarios that combine experimental data and modeling of population dynamics [46]. The positive results for interaction of planting dates and treatments support the second hypothesis of this study, and represent a viable farm-level integrated pest management adaptation to current climate dynamics in the study area.

Effect of treatments on cabbage pests

The ecology of insect pests is highly influenced by temperature, which may either enhance reproduction or decrease mortality of insects, leading to stronger infestations [47, 48]. Climate dynamics can lead to the emergence of new species such as the South American tomato leaf miner *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) that occurred in Europe [49]. Generally, intercropping, *Piper* emulsion and insecticide

Table 4 Effect of planting dates—A (early, normal and late) and treatments—B (control, intercropping, *Piper* emulsion and insecticide) on number of sprouted cabbage plants (mean ± SD)

A

Treatments	Planting dates		
	Early	Normal[a]	Late
Control	6.2 ± 1.7c	5.0 ± 1.1b	0.7 ± 0.9a
Intercropping	0.5 ± 0.5b	1.0 ± 0.0a	0.2 ± 0.5a
Piper emulsion	1.2 ± 0.9b	1.0 ± 0.5a	0.0 ± 0.0a
Insecticide	1.0 ± 0.9b	0.5 ± 0.5a	0.0 ± 0.0a

B

Planting dates	Treatments			
	Control	Intercropping	*Piper* emulsion	Insecticide
Early	6.2 ± 1.7c	0.5 ± 0.5b	1.2 ± 0.9b	1.0 ± 0.9b
Normal	5.0 ± 1.1b	1.0 ± 0.0a	1.0 ± 0.5a	0.5 ± 0.5a
Late	0.7 ± 0.9a	0.2 ± 0.5a	0.0 ± 0.0a	0.0 ± 0.0a

Values within rows with different letters are significantly different ($P < 0.05$)

[a] Data taken from Tanyi et al. [35]

demonstrated efficacy as control measures for cabbage pests against the control, irrespective of the planting dates [18]. Tomato intercropping could be considered as the most affordable and cost-effective pest management strategy in relation to the other treatments. The impact of tomato intercropping is likely due to the confusing olfactory and visual cues from tomato plants that repelled cabbage pests [18, 50]. *P. guineense* contains isobutyl amide plant secondary metabolites (e.g. piperine, piperiline and natural lipophilic amides) that act as neurotoxins in insects [51–53], which likely resulted in the efficacy of *Piper* emulsion against insect pests across planting dates. This effect of *Piper* emulsion on cabbage infestation and pest occurrence is consistent with reports on the efficacy of *Piper* [54, 55]. These results strongly support the second hypothesis of this study that advocates a combination of alternative planting dates and *Piper* emulsion or intercropping as farm-level adaptation to control cabbage pests under current climate variability in the study area.

Interactive effects of planting dates and treatments on cabbage

Cabbage performance was consistent with the rate of pest infestation, with increased cabbage yield as pest infestation decreased and vice versa. The significantly low number of sprouted plants and high yield during late planting compared to normal and early plantings is consistent with the first hypothesis that suggests a shift in planting dates in the study area. This can be attributed to changes in climate variables such as temperature and rainfall that reduced pest larvae below economic threshold [43, 45]. Cabbage performance is consistent with the second hypothesis of this study that advocates greater cabbage yield due to tomato intercropping as companion crop. Low cabbage yield in the control is consistent with high pest infestation, which corresponds to high leaf and head damage that likely reduced photosynthetic carbon fixation and plant growth [56]. Looper and webworm are considered major yield-reducing cabbage pests, which is consistent with the significant cabbage damage that is comparable to DBM damage, especially during early and late plantings [11]. The increasing cabbage yield from early to late plantings in Cabbage–tomato intercrop compared to insecticide and *Piper* treatments is inconsistent with the recorded trend of pest infestation, which suggests additional factors that improved cabbage yield. The decomposition of dead tomato plants after complete pest damage in the sole tomato and Cabbage–tomato intercrop treatments likely improved soil fertility, plant nutrition and biological processes that favoured cabbage yield [57]. Overall, the relatively high cabbage yield recorded in the late planting and cabbage–tomato intercrop treatment highlights the importance of integrating alternative planting dates and treatments under climate change scenarios.

Conclusion

The interaction of planting dates and *Piper* emulsion or intercropping treatments can be effectively used to control cabbage pests and improve yields, with the late

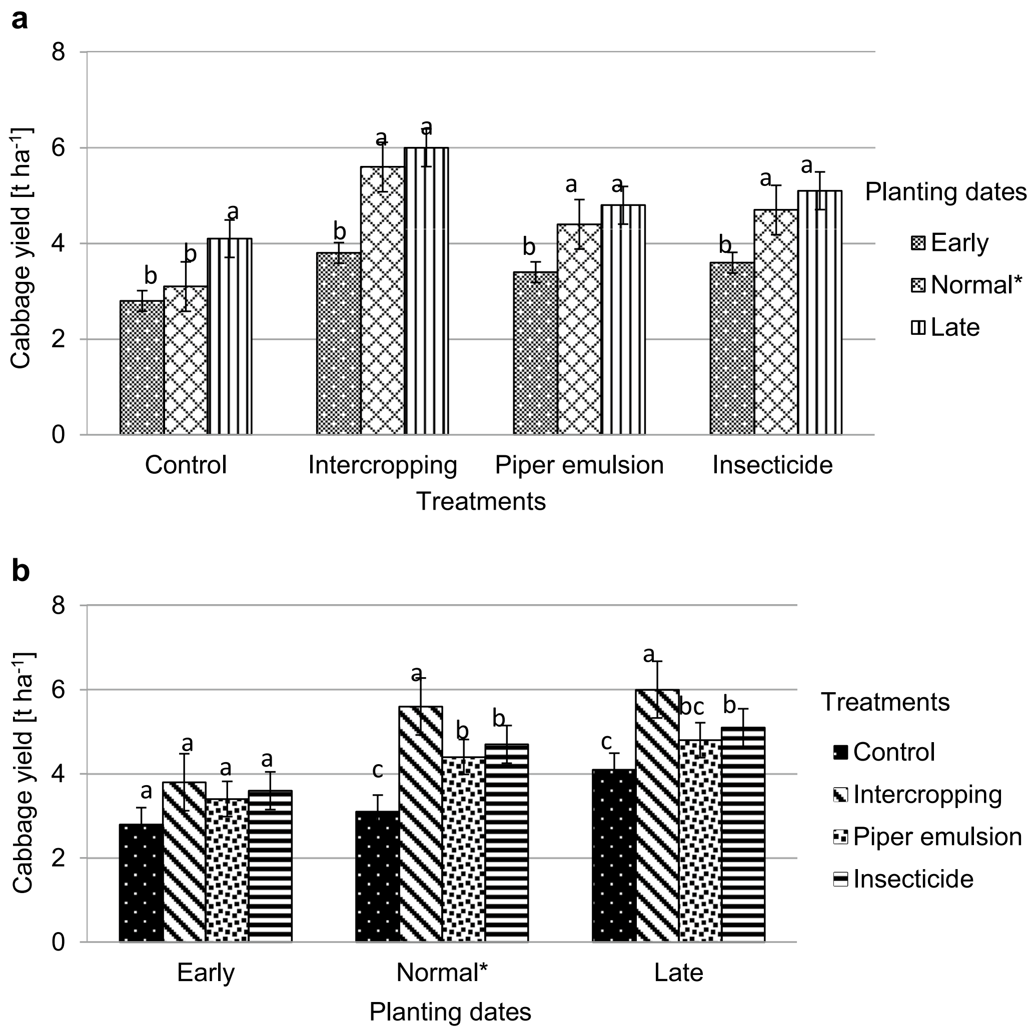

Fig. 3 Impact of planting dates (**a**) (early, normal and late) and treatments (**b**) (control, intercropping, *Piper* emulsion and insecticide) on cabbage yield (t ha^{-1}, mean ± SD); values within treatments or planting dates with different letters are significantly different ($P < 0.05$). *Data from Tanyi et al. [35]

planting date as viable alternative farm-level adaptation to climate variability. These represent cost-effective and environmentally friendly pest management strategy that can be adopted by farmers to control cabbage pests below economic injury threshold and improve yield.

Abbreviations
DBM: diamondback moth; SSA: sub-Saharan Africa; PAMS: prevention, avoidance, monitoring and suppression; SD: standard deviation; ANOVA: analysis of variance; NPK: nitrogen, phosphorus and potassium.

Authors' contributions
This work was carried out in collaboration between all authors. CBT designed, established and managed the experiment, prepared botanical, performed harvest and data collection, processed and analysed data, performed literature searches and wrote the first manuscript draft. CN contributed in experimental design, data processing and statistical analyses, conducted literature searches and coordinated preparation of first manuscript draft. NNN contributed in the experimental design, coordinated the field experimentation and data collection, and supervised manuscript preparation and the overall study. All authors read and approved the final manuscript.

Acknowledgements
We extend gratitude to the Faculty of Agriculture and Veterinary Medicine, University of Buea, and the Ministry of Higher Education–MINESUP Cameroon for Research Grants.

Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
All data generated or analysed during this study are included in this published article.

Consent for publication
Not applicable.

Ethics approval and consent to participate
Not applicable.

Funding
Not applicable.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Received: 22 September 2018 Accepted: 3 December 2018
Published online: 10 December 2018

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