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Research article

Effect of blended NPS fertilizer and cattle manure on soil property and hot pepper productivity in Jabi Tehnan Ethiopia

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ABSTRACT

Hot pepper is one of the most important spice vegetable crops in Ethiopia and is widely cultivated for dry pod production. However, its productivity is low in Ethiopia due to degraded soil fertility and an unbalanced nutrient supply in the soil. An experiment was conducted to evaluate the effect of NPS fertilizer and cattle manure (CM) on soil chemical properties and hot pepper dry pod yield under irrigation in Jabi Tehnan. This experiment was arranged in factorial combinations of four NPS fertilizer (0, 100, 200, and 300 kg ha^{-1}) and four CM (0, 5, 10, and 15 t ha^{-1}) levels in a randomized complete block design with three replicates. Soil chemical properties, hot pepper phenology, growth, yield, and yield-related traits were recorded and analyzed using SAS software version 9.4. The main and interaction effects of NPS and CM fertilizers had a significant effect on soil chemical properties, hot pepper phenology, growth, yield, and yield-related traits. The combination of NPS fertilizer and CM significantly increased soil chemical properties and hot pepper traits. However, soil chemical properties and hot pepper yield traits showed a somewhat decreasing trend as the combination levels of two fertilizers further increased. The highest marketable (2.90 t ha^{-1}) and total dry pod yield (2.99 t ha^{-1}) were produced at the combination of 200 kg NPS ha^{-1} and 15 t CM ha^{-1}. However, the partial budget analysis showed that the combination of 200 kg NPS ha^{-1} and 10 t CM ha^{-1} had the highest net benefit with an acceptable MRR and can be recommended for profitable hot pepper dry pod production in the study area. However, the experiment was limited to a single location and variety; it should be repeated at multiple locations over the seasons to make a strong recommendation.

1. Introduction

Hot pepper (*Capsicum annum* L.) belongs to the nightshade family Solanaceae and genus *Capsicum* and is a significant vegetable and spice crop worldwide due to its flavor, aroma, and pungency [1,2]. Behind tomatoes, hot pepper is the second-important vegetable crop in the Solanaceae family worldwide. Its pod is a source of vital vitamins, minerals, and antioxidant compounds [3,4]. In Ethiopia, fresh green hot pepper pods have been consumed as vegetables with other foods for nutritional and medicinal purposes [5]. Hot pepper dry pods are also widely used in Ethiopia as spice in the form of fine powder (berbere) to flavor and color daily pulps [6–8]. In addition to its nutritional, medicinal, and spicy uses, hot pepper is also used for income generation at the farmer and commercial scales in

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Ethiopia [9,10].

Most Ethiopian agroecosystems are suitable for hot pepper dry and green pod production both in home gardens and at the commercial level under rain-fed and irrigation conditions [10,11]. Hot pepper is produced across Ethiopia, especially in the provinces of Oromia, Amhara, Somalia, and the southern region of the country (11, 12]. However, the hot pepper productivity of both dry (1.8 t ha^{-1}) and green (6.31 t ha^{-1}) pods in Ethiopia [13] is low compared to the global average dry (2.57 t ha^{-1}) and green (17.8 t ha^{-1}) pod productivity [14]. Low hot pepper productivity in Ethiopia is due to soil fertility degradation, poor agronomic practices, a lack of improved varieties, and disease and pest infestation [15–17]. However, soil fertility degradation and unbalanced nutrient supply to the soil are the main problems limiting hot pepper productivity in Ethiopia [2,18].

Balanced soil fertilization is crucial to improving hot pepper productivity in Ethiopia [19,20]. Hence, hot pepper requires balanced plant nutrients, including nitrogen (N), phosphorus (P), sulfur (S), potassium (K), and micronutrients, for normal growth and development to attain maximum productivity [5]. However, most Ethiopian highland soils encompassed in the study area are deficient in N, P, and S and other essential micronutrients as a result of drastic leaching due to prolonged abundant precipitation [21,22], and long-term frequent cultivation [23]. Furthermore, for the past 50 years, Ethiopian farmers have used 150 kg ha^{-1} diammonium phosphate (DAP) and 100 kg ha^{-1} urea fertilizer in hot pepper production across the country as a national recommendation [10,17]. However, such recommendations do not account for soil type and fertility, climatic conditions, crop type, or any other factors that could affect fertilizer amounts, and only applying N and P sources of fertilizer to the soil is insufficient to satisfy hot pepper nutrient requirements [5,24]. Therefore, in order to improve hot pepper productivity in Ethiopia, it is crucial to use other fertilizer sources beyond DAP and urea, which contain sulfur and other vital micronutrients in addition to N and P [23]. As a result, in place of DAP, the Ethiopian Ministry of Agriculture has currently introduced a new blended NPS fertilizer that contains 19 % N, 38 % P, and 7 % S to improve crop productivity, including hot pepper in Ethiopia [23]. Limited study reports also suggested that hot pepper productivity was increased by applying 200 kg NPS ha^{-1} in southern Ethiopia [16]. Moreover, application of 150 kg NPS ha^{-1} combined with 150 kg N ha^{-1} increased hot pepper dry pod productivity in west Wollega, Ethiopia [5]. However, it is commonly known that excessive and prolonged use of inorganic fertilizers is expensive, degrades soil and raises its acidity or alkalinity, reduces soil microbial biomass and activity, and causes groundwater pollution problems due to excessive nutrient leaching and reduced sustainable soil productivity [25–27]. Consequently, it is not sustainable to produce crops solely using inorganic fertilizers. For this reason, the use of organic manure as a full or partial replacement for inorganic fertilizers is both cost-effective and environmentally safe [28].

Organic manure is a byproduct of animal waste and a source of both macro and micro plant nutrients that aid in promoting plant growth, development, and crop productivity [29,30]. It can also improve soil aggregation, soil organic carbon, fertility, porosity, water infiltration capacity, and soil microbial populations and biomass [31,32]. However, the nutrient content of organic manure fertilizer is relatively low compared to inorganic fertilizers, and it has a poor ability to release nutrients quickly enough to meet crop requirements [33]. As a result, applying organic manure alone would not be able to fulfill the typical intensity of agriculture production [34,35]. Therefore, combining inorganic fertilizers with organic manure is advantageous and vital for sustainable agricultural soil management strategies that permit present crop production with rising productivity without impeding future production strategies [30]. Previous studies have shown that the combined application of 50 % of the recommended NP fertilizer with 5 t of farmyard manure (FYM) ha^{-1} improved hot pepper dry pod yield [24]. Likewise [11], reported that the combined application of 100 kg NPS ha^{-1} and 5 t CM ha^{-1} increased hot pepper dry pod yield in Ethiopia. Furthermore, compared to applying inorganic fertilizers alone, the combined application of inorganic and organic fertilizers improved the soil's physiochemical properties [36,37]. However, there is a dearth of information regarding the use of blended NPS fertilizer and cattle manure (CM) for hot pepper dry pod production in Jabi Tehnan District, west Gojam, Ethiopia. Therefore, this research was initiated to determine the effect of blended NPS and CM fertilizers on soil chemical properties and hot pepper dry pod yield in Jabi Tehnan District under irrigation conditions.

2. Materials and methods

2.1. Description of the study area

The experiment was conducted in Jabi Tehnan district, west Gojam, Ethiopia in 2020/21 under irrigation. The district is located at 10°40′0″N latitude and 37°8′0″E longitude, with an elevation of 1900 m above sea level, and has a silty clay soil type. The mean annual minimum and maximum air temperatures of the area were 14 and 32 °C, respectively. The annual rainfall and mean temperature are 1250 mm and 23 °C, respectively [12]. The experimental site's soil was silty clay and had a pH of 5.60, which was considered

Table 1
Soil physicochemical and cattle manure chemical properties before the experiment.

Soil (0–20 cm) and CM properties	Soil value	Rating	CM value	Rating	Reference
pH (H_20)	5.6	Moderately acidic	7.6	Moderately alkaline	[38]
TN (%)	0.12	Low	1.34	Very high	[39]
AP (ppm)	13.76	Medium	106.04	Very high	[40]
OC (%)	2.15	Medium	15.65	Very high	[39]
OM (%)	3.69	Medium	26.92	Very high	[39]
CEC (meq/100 gm)	30.42	High	38.4	high	[41]
Sand: silt: clay (%)	19: 40: 41	Silty clay textural class			[42]

CM, cattle manure; TN, total nitrogen; AP, available phosphorus; OC, organic carbon; OM, organic matter; CEC, cation exchange capacity.

moderately acidic. In addition, the soil had low (0.12 %) total nitrogen (TN), medium (13.76 ppm) available phosphorus (AP), (2.15 %) organic carbon (OC), and (3.69 %) organic matter (OM), and high (30.42 meq/100 gm) cation exchange capacity (CEC) (Table 1).

2.2. Experimental materials

The Mareko Fana hot pepper variety was used in this experiment. The variety was released at the Melkasa Agricultural Research Center (MARC) in 1976. It has a larger, dark red, thick cover pod with a strong pungent flavor and is highly favored by consumers due to its high powder yield, pungency, and beautiful hue [24]. Furthermore, the variety is more adaptable and thrives at elevations between 1200 and 2000 m above sea level, with an annual precipitation of 600–1337 mm [43]. The variety has good branching habits and matures in 110–130 days after transplant [44].

2.3. Treatments and experimental design

The treatments consisted of four blended NPS fertilizer levels (0, 100, 200, and 300 kg ha^{-1}) and four CM levels (0, 5, 10, and 15 t ha^{-1}). The two fertilizer levels were determined based on the national recommendation of 200 kg NPS ha^{-1} and 10 t FYM ha^{-1} for hot pepper production [24]. The CM was obtained at the Jabi Tehnan farmer training center, and before being used as a treatment, its chemical properties and nutrient content were tested in a soil laboratory. Based on the tested result, the CM was moderately alkaline with a pH of 7.6, and it contained very high OM (26.92 %), OC (15.65 %), AP (106.04 ppm), TN (1.34 %), and CEC (38.4 meq/100 gm) (Table 1). The experiment was laid out in a randomized complete block design with three replications. The plot size was 8.4 m^2 (2.4 m × 3.5 m). The space between plots and blocks was 0.5 m and 1 m, respectively, and the treatments were assigned randomly to each plot. Each plot has five rows, with eight plants in each row.

2.4. Experimental procedures and crop managements

The Mareko Fana pepper variety seeds were sown by hand near the main experimental field in well-prepared nursery beds of 1 m width by 5 m length at an inter-row spacing of 8 cm to produce seedlings [18]. The bed was covered by dry grass mulch to conserve moisture and enhance seed germination, and it was regularly irrigated. The mulch material was removed after seedlings emerged and covered the seedlings with shade at a height of 1.5 m. All other management practices were applied as required until the seedlings were ready for transplanting [45].

The experimental field was plowed three times using a pair of oxen, leveled manually, and irrigated one day before seedling transplanting. On December 5, 2020, vigor and healthy seedlings with a 20–25 cm height were planted on ridges with a spacing of 70 cm between rows and 30 cm between plants [45]. Transplanting was done in the late afternoon to reduce plant shock. Based on the treatment, 3 weeks before transplanting the seedlings, the entire amount of CM was applied and properly mixed into the soil at a depth of 15–20 cm, and NPS fertilizer was applied to each plant during transplanting in a circular band 5 cm apart from the seedling [46]. Furrow irrigation was applied every 1–3 days for the first two weeks, and later, the irrigation gap was increased to a 3- to 7-day interval throughout the crop-growing period [47]. All agronomic and cultural practices were performed uniformly for all plots [45]. Pod harvesting was started on March 20, 2021, by handpicking when the pod turned red [45]. Pods were harvested five times throughout the growing season of the crop.

2.5. Soil and cattle manure sampling and analysis

Surface soil samples were randomly collected in a zigzag pattern at a depth of 0–20 cm using an auger before planting in the entire plot and in each plot after the hot pepper pod was harvested. A CM sample was taken randomly from the top, middle, bottom, and each side of the mound. Pre-plant soil and CM samples before transplanting, as well as treatment-based soil samples after crop harvesting, were sent to the Debre-Markos soil testing and fertility improvement laboratory center. One kilogram (1 kg) of the composite sample for each was used for the final laboratory to analyze soil texture, OC, OM, TN, AP, pH, and CEC. Soil texture was analyzed using the Bouyoucos hydrometer method [48]. The pH was determined potentiometrically in a supernatant with a 1:2.5 soil-to-water ratio using a combined glass electrode and pH meter [49]. TN was determined using the wet oxidation step of the Kjeldhal method [50]. The Olsen method was used to determine the available phosphorus (AP) [51]. The CEC was determined using the ammonium acetate method as described by Ref. [52]. The OC was determined using the wet digestion method [53]. Using similar analytical techniques to determine soil chemical properties after the crop was harvested.

2.6. Data collection

2.6.1. Phenology and growth traits

Days to 50 % flowering (Days): The actual count of the number of days from transplanting to the date when about 50 % of the plants in a plot started blooming.

Days to 50 % pod setting (Days): The number of days from the date of transplanting up to the date when 50 % of plants in the plot started producing at least one green pod was counted.

Days to 90 % pod maturity (Days): Counted the number of days from the transplanting up to the date when 90 % of the plants attained at least one physiologically mature pod.

Plant height (cm): It was measured in centimeters from the soil surface to the top growth points of the above ground plant part from ten randomly selected plants at the last harvest.

Number of branches per plant: The number of primary and secondary branches counted from ten randomly selected plants was recorded at the last harvest.

2.6.2. Yield and yield-related traits

Number of pods per plant: The number of pods per plant was counted from ten randomly selected and tagged plants at each harvest, and mean values were computed.

Pod length (cm): The average lengths of the pod measured from the tip of the fruit to the basal end of ten randomly selected pods at each harvest were recorded, and the mean value was computed.

Pod width (cm): The diameter of ten randomly selected pods was measured in the middle of each pod at each harvest using a digital caliper, and the mean value was computed.

Number of seeds per pod: Seeds extracted from ten randomly selected pods were counted at each harvest, and mean values were computed.

Marketable dry pod yield (t ha^{-1}): Pods which are free from insect damaged, unbleached, uniform color and relatively larger size fruits are considered as marketable [54]. Such pods were weighed at each successive harvest using scale balance after drying at 70 °C for 20 h with a 10 % moisture content [55].

Unmarketable dry pod yield (t ha^{-1}): Pods that are small in size, cracked, discolored, and shrunken in shape were considered unmarketable [18]. Such pods were weighed at each successive harvest using scale balance after drying and recorded as unmarketable yield.

Total dry pod yield (t ha^{-1}): The weight of total (marketable and unmarketable) pods from each successive harvest was measured and recorded to estimate the total dry pod yield and expressed in t ha^{-1}.

2.7. Data analysis

Prior to data analysis, a normality test was conducted with the Shapiro-Wilk test, and the normality assumption of all data was not violated. All data were subjected to analysis of variance and correlation of yield with phenology, growth, and yield-related traits using SAS version 9.4 statistical software with the procedures described by Gomez and Gomez [56]. Mean separations were conducted using the least significant difference at a 5 % probability level.

2.8. Partial budget analysis

Partial budget was calculated through the procedures described by Ref. [57]. The marginal rate of return (MRR) for each pair of treatments was calculated as a change in net benefit divided by the change in the cost of treatment. Thus, the treatment with the highest net benefit, non-dominant, and MRR value greater or equal to 100 % was taken to be economically profitable.

Table 2
Mean square analysis value effects of NPS fertilizer and cattle manure on soil chemical properties and hot pepper phonology, growth, yield and yield-related traits in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation.

Soil chemical properties after the crop harvested	NPS fertilizer kg ha^{-1},DF = 3	Cattle manure t ha^{-1}, DF = 3	NPS fertilizer kg ha^{-1}*Cattle manure t ha^{-1}, DF = 9
pH ($H_2$0)	0.04**	0.77**	0.02**
Total nitrogen (%)	0.004**	0.04**	0.001**
Available phosphorus (ppm)	6.09**	26.02**	1.04*
Organic carbon (%)	0.39**	2.64**	0.06**
Organic matter (%)	1.15**	7.8**	0.19**
Cation exchange capacity (meq/100 gm)	105.84**	171.56**	34.68**
Crop traits			
Days to 50 % flowering (days)	120.50**	139.55**	4.27*
Days to 50 % pod setting (days)	269.27**	246.72**	17.70**
Days to 90 % maturity (days)	380.47**	764.47**	17.15**
Plant height (cm)	279.07**	385.41**	17.08*
Number of primary branches per plant	10.24**	6.81**	0.42**
Number of secondary branches per plant	40.78**	45.55**	1.63**
Number of pods per plant	126.47**	112.32**	5.03*
Pod length (cm)	6.20**	5.93**	0.54*
Pod width (cm)	0.76**	1.01**	0.03*
Number of seeds per pod	2465.58**	3238.65**	139.6**
Marketable dry pod yield (t ha^{-1})	2.08**	1.87**	0.09**
Unmarketable dry pod yield (t ha^{-1})	0.06**	0.11**	0.01**
Total dry pod yield (t ha^{-1})	1.43**	1.09**	0.05*

DF, Degree of freedom.
* and **, significant at $p < 0.05$ and $p < 0.01$, respectively.

3. Results

The analysis of variance (ANOVA) revealed that the main and interaction effects of NPS fertilizer and CM significantly affected soil chemical properties and hot pepper phenology, growth, yield and yield-related traits (Table 2).

3.1. Effect of blended NPS fertilizer and cattle manure on soil chemical properties

3.1.1. Soil organic carbon, organic matter, total nitrogen, and available phosphorus

The main and interaction effects of NPS fertilizer and CM had a significant effect on soil OC, OM, TN, and AP after hot pepper was harvested (Table 2). The highest soil OC, OM, TN, and AP were observed in the plot fertilized with the combination of 200 kg NPS ha^{-1} and 15 t CM ha^{-1}, which were statistically similar to the plot fertilized with the combination of 200 kg NPS ha^{-1} and 10 t CM ha^{-1}. Higher soil OM and OC, and TN were also recorded in the plot fertilized with 300 kg NPS ha^{-1} plus 15 t CM ha^{-1} and100 kg NPS ha^{-1} plus 15 t CM ha^{-1}, respectively, and statistically similar to the plot fertilized with the combination of 200 kg NPS ha^{-1} and 15 t CM ha^{-1}. On the other hand, the lowest soil OC, OM, TN, and AP were recorded in the unfertilized plot (control treatment) (Table 3). In general, both the sole and combined application of NPS fertilizer and CM enhanced soil OC, OM, TN, and AP over unfertilized plot, but they showed a slight decreasing trend when the combination level of the two fertilizers was increased.

3.1.2. Soil cation exchange capacity

After the hot pepper was harvested, soil CEC was significantly affected by the application of NPS fertilizer and CM and by their interaction (Table 2). The highest CEC was obtained in the plot fertilized with the combination of 100 kg NPS ha^{-1} and 15 t CM ha^{-1}, which showed statistical similarity with the plots fertilized with 200 kg NPS ha^{-1} plus 10 t CM ha^{-1} and 300 kg NPS ha^{-1} plus 10 t CM ha^{-1}. Conversely, the lowest soil CEC was recorded in the unfertilized plot (Table 3). Both the sole and combined application of NPS fertilizer and CM generally increased soil CEC relative to the unfertilized plot, but it showed a slight decreasing trend as the combination level of the two fertilizers further increased.

3.1.3. Soil pH

The main and interaction effects of NPS fertilizer and CM significantly affected soil pH after hot pepper was harvested (Table 2). The highest (5.83) soil pH was recorded in the plot fertilized with the combination of 200 kg NPS ha^{-1} and 10 t CM ha^{-1}, which was statistically similar to the plots fertilized with 15 t CM ha^{-1}, 100 kg NPS ha^{-1} plus 15 t CM ha^{-1}, and 200 kg NPS ha^{-1} plus 15 t CM ha^{-1}. On the other hand, the lowest (5.02) soil pH was recorded in the plot fertilized with 300 kg NPS ha^{-1}, which was statistically similar to the plot fertilized with 200 kg NPS ha^{-1} (Table 3). In general, the combined application of NPS fertilizer and CM increased soil pH significantly, but it showed inconstancy and a slight decrease when the NPS fertilizer level increased. The sole application of CM with an increasing level also slightly increased the soil pH compared to unfertilized plot and fertilized plots with NPS fertilizer.

Table 3

Interaction effect of NPS fertilizer and CM on soil organic carbon, organic matter, total nitrogen, available phosphorus, cation exchange capacity and soil pH after hot pepper was harvested in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation.

Treatment		Soil properties (0–20 cm)					
NPS (kg ha^{-1})	CM (t ha^{-1})	OC (%)	OM (%)	TN (%)	AP (ppm)	CEC (meq/100 gm)	pH (H_20)
0	0	1.69^{g}	2.90^{g}	0.08^{j}	13.26^{g}	24.00^{f}	5.31^{f}
	5	2.04^{f}	3.51^{f}	0.13^{gh}	13.86^{fg}	24.80^{ef}	5.61^{cd}
	10	2.16^{ef}	3.71^{ef}	0.16^{efg}	14.54^{ef}	32.33^{d}	5.66^{bc}
	15	2.59^{cd}	4.45^{cd}	0.20^{cd}	15.85^{dc}	35.10^{c}	5.72^{abc}
100	0	1.76^{g}	3.02^{g}	0.09^{ij}	13.53^{fg}	32.43^{d}	5.21^{fg}
	5	2.33^{e}	3.75^{ef}	0.16^{ef}	15.05^{de}	26.60^{e}	5.63^{bcd}
	10	2.60^{c}	4.47^{c}	0.18^{de}	16.22^{c}	31.26^{d}	5.69^{bc}
	15	2.68^{bc}	4.60^{bc}	0.23^{ab}	16.62^{c}	40.96^{a}	5.75^{ab}
200	0	1.75^{g}	3.01^{g}	0.10^{ij}	13.53^{fg}	35.54^{c}	5.12^{gh}
	5	2.33^{e}	4.00^{e}	0.15^{fg}	15.06^{de}	30.96^{d}	5.47^{e}
	10	3.01^{a}	5.18^{a}	0.25^{a}	17.83^{ab}	39.53^{a}	5.83^{a}
	15	3.06^{a}	5.26^{a}	0.25^{a}	17.94^{a}	35.80^{c}	5.73^{abc}
300	0	1.79^{g}	3.07^{g}	0.12^{hi}	13.78^{fg}	30.26^{d}	5.02^{h}
	5	2.36^{de}	4.05^{de}	0.16^{efg}	15.06^{de}	34.96^{c}	5.53^{de}
	10	2.74^{bc}	4.71^{bc}	0.20^{cd}	16.76^{bc}	38.83^{ab}	5.61^{dc}
	15	2.86^{ab}	4.92^{ab}	9.22^{bc}	16.44^{c}	36.80^{bc}	5.66^{bcd}
LSD (5 %)		0.24	0.41	0.02	1.15	2.23	0.13
CV (%)		6.19	6.17	9.38	4.51	4.05	1.39

CM, cattle manure; LSD, least significant difference at 5% probability level; CV (%), coefficient of variation in percent; OC, organic carbon; OM, organic matter; TN, total nitrogen; AP, available phosphorus; CEC, cation exchange capacity; means following by the same letter (s) in a column are not significantly different $p < 0.05$.

3.2. Effect of blended NPS fertilizer and cattle manure on crop phenology and growth traits

3.2.1. Days to 50 % flowering and pod setting

According to the ANOVA, hot pepper days to 50 % flowering and pod setting were significantly affected by NPS fertilizer, CM, and their interaction (Table 2). The earliest days to 50 % flowering and pod setting were observed on an unfertilized plot. Earlier flowering and pod setting were also observed in the plot fertilized with 5 t and 10 t CM ha^{-1}, respectively, which showed statistical similarities with the unfertilized plot. On the other hand, delayed days to 50 % flowering were observed in the plot fertilized with the combination of 300 kg NPS ha^{-1} and 15 t CM ha^{-1}, which was statistically similar to the combination of 300 kg NPS ha^{-1} and 10 t CM ha^{-1} and 200 kg NPS ha^{-1} and 15 t CM ha^{-1}. Similarly, delayed days to 50 % pod setting were recorded in the plot fertilized with a combination of 300 kg NPS ha^{-1} and 15 t CM ha^{-1},which was statistically at par with the combination of 200 kg NPS ha^{-1} and 15 t CM ha^{-1}. Generally, hot pepper days to flowering and pod setting displayed a delayed trend with increasing levels of NPS fertilizer and CM, both in sole and combined application, compared to the unfertilized plot (Table 4).

3.2.2. Days to 90 % pod maturity

The ANOVA indicted that NPS fertilizer, CM and their interaction had a significant effect on hot pepper days to 90 % pod maturity (Table 2). Hot pepper grown in an unfertilized plot had the earliest days to 90 % pod maturity, which was statistically in parity with the plot fertilized with 100 kg NPS ha^{-1} and 5 t CM ha^{-1}. In contrast, hot pepper grown in a plot fertilized with a combination of 300 kg NPS ha^{-1} and 15 t CM ha^{-1} showed a delayed 90 % pod maturity, which was statistically at par with the combination of 300 kg NPS ha^{-1} and 10 t CM ha^{-1} and 200 kg NPS ha^{-1} and 15 t CM ha^{-1} (Table 4).

3.2.3. Plant height

The ANOVA revealed that the main and interaction effects of NPS fertilizer and CM had a significant effect on hot pepper plant height (Table 2). The highest plant height was recorded from the plot fertilized with a combination of 300 kg NPS ha^{-1} and 15 t CM ha^{-1}. This was statistically similar to the plots fertilized with a combination of 200 kg NPS ha^{-1} and 15 and 10 t CM ha^{-1}, 100 kg NPS ha^{-1} and 15 t CM ha^{-1}, and 300 kg NPS ha^{-1} and 10 t CM ha^{-1}. However, the lowest plant height was recorded in the unfertilized plot, which was statistically at par with the plots fertilized with 100 and 200 kg NPS ha^{-1} and 5 and 10 t CM ha^{-1}. Totally, hot pepper plant height display an increasing tendency due to the sole and combined application of NPS fertilizer and CM at increasing levels over an unfertilized plot (Table 5).

3.2.4. Number of primary and secondary branches per plant

The main and interaction effects of NPS fertilizer and CM significantly affected hot pepper primary and secondary branch numbers per plant (Table 2). The plot fertilized with the combination of 300 kg NPS ha^{-1} and 15 t CM ha^{-1} had the highest primary and secondary branch numbers per plant. These were statistically similar to the primary and secondary branch numbers per plant obtained from the plot fertilized with the combination of 200 kg NPS ha^{-1} and 15 t CM ha^{-1}. On the other hand, the unfertilized plot had the fewest primary and secondary branches per plant, which were statistically similar to the plots that were fertilized with 5 and 10 t CM ha^{-1}. Similarly, the plot fertilized with 100 kg NPS ha^{-1} had lower secondary branch numbers per plant, which was statistically similar to the unfertilized plot. Overall, the solo and combination applications of NPS fertilizer and CM with increasing levels over an

Table 4
Interaction effects of NPS fertilizers and cattle manure on phenological traits of hot pepper in Jabi Tehnan District, Ethiopia in 2020/21 under irrigation.

Treatment			Phenological Traits	
NPS (kg ha^{-1})	CM (t ha^{-1})	Days to 50 % flowering (days)	Days to 50 % pod setting (days)	Days to 90 % pod maturity (days)
0	0	53.00^{j}	82.67^{i}	103.00^{h}
	5	54.00^{ij}	88.33^{fgh}	105.00^{gh}
	10	55.67^{hi}	85.67^{hi}	109.00^{f}
	15	59.33^{ef}	90.00^{efg}	118.00^{de}
100	0	56.00^{ghi}	87.66^{gh}	104.67^{gh}
	5	55.66^{hi}	87.00^{gh}	111.00^{f}
	10	63.67^{bc}	96.67^{cd}	121.00^{dc}
	15	63.66^{bc}	96.33^{cd}	123.33^{bc}
200	0	57.67^{fgh}	89.67^{fgh}	108.00^{gf}
	5	60.67^{de}	92.33^{def}	116.33^{e}
	10	63.67^{bc}	98.67^{cd}	125.67^{ab}
	15	65.00^{ab}	101.33^{ab}	126.30^{ab}
300	0	58.00^{fg}	92.33^{def}	126.30^{ab}
	5	61.00^{de}	93.33^{de}	119.33^{de}
	10	65.33^{ab}	99.00^{bc}	127.67^{a}
	15	66.00^{a}	105.00^{a}	129.33^{a}
LSD (5 %)		2.04	4.05	3.89
CV (%)		2.05	2.62	2.01

CM, cattle manure; LSD, least significant difference at 5 % probability level; CV (%), coefficient of variation in percent, means following by the same letter (s) in a column are not significantly different $p < 0.05$.

Table 5
Interaction effects of NPS fertilizer and cattle manure on growth traits of hot pepper in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation.

Treatment		Growth traits		
NPS (kg ha^{-1})	CM (t ha^{-1})	Plant height (cm)	Number of primary branch	Number of secondary branch
0	0	43.80^{g}	2.98^{j}	3.99^{i}
	5	47.20^{efg}	3.53^{ij}	4.53^{i}
	10	46.50^{fg}	3.60^{hij}	5.12^{hi}
	15	50.73^{e}	3.77^{ghi}	6.17^{gh}
100	0	45.20^{fg}	4.17^{fgh}	4.33^{i}
	5	55.23^{d}	4.40^{f}	7.10^{fg}
	10	58.60^{bcd}	5.12^{de}	8.62^{de}
	15	59.33^{abcd}	5.63^{cd}	10.13^{bc}
200	0	46.10^{fg}	4.27^{fg}	6.10^{gh}
	5	56.87^{cd}	4.50^{ef}	7.93^{ef}
	10	60.50^{abc}	5.47^{cd}	9.26^{cd}
	15	62.13^{ab}	6.36^{ab}	11.29^{ab}
300	0	48.87^{ef}	4.33^{fg}	6.42^{g}
	5	57.37^{cd}	5.26^{d}	8.50^{de}
	10	62.50^{ab}	5.94^{bc}	9.43^{cd}
	15	63.01^{a}	6.94^{a}	11.83^{a}
LSD (5 %)		4.20	0.63	1.23
CV (%)		4.67	7.96	9.82

CM, cattle manure; LSD, least significant difference at 5 % probability level; CV (%), coefficient of variation in percent, means following by the same letter (s) in a column are not significantly different at $p < 0.05$.

unfertilized plot showed an increasing tendency for hot pepper primary and secondary branch numbers per plant (Table 5).

3.3. Yield and yield-related traits

3.3.1. Number of pods per plant

Hot pepper pod numbers per plant were significantly influenced by NPS fertilizer and CM, as well as by the two interactions (Table 2). The highest (32.17) pod numbers per plant were recorded from the plot fertilized with a combination of 300 kg NPS ha^{-1} and 15 t CM ha^{-1}, which was statistically similar to pod numbers per plant obtained from the plots fertilized with the combination of 200 kg NPS ha^{-1} and 15 t CM ha^{-1} and 300 kg NPS ha^{-1} and 10 t CM ha^{-1}. However, the lowest (19.00) pod numbers per plant were observed in the unfertilized plot, and it was statistically similar to the plots fertilized with 100 kg NPS ha^{-1}, 5 and 10 t CM ha^{-1} (Fig. 1).

3.3.2. Pod length, width and seed numbers per pod

Both the interaction and main effect of NPS fertilizer and CM had a significant effect on hot pepper pod length, width and seed numbers per pod (Table 2). The plot fertilized with the combination 200 kg NPS ha^{-1} and 15 t CM ha^{-1} had the longest (10.30 cm) and widest (2.75 cm) pod and the highest (143.53) seed numbers per pod, which was statistically in parity with the plots receiving 200 kg

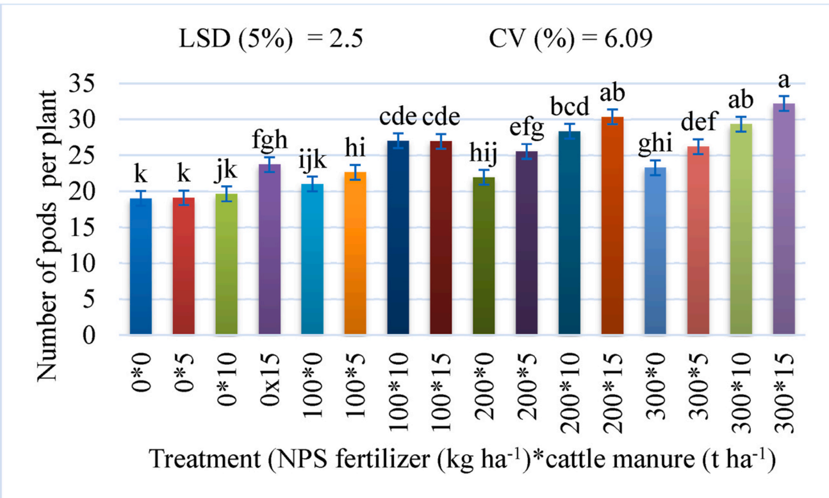

Fig. 1. Interaction effect of NPS fertilizer and CM on hot pepper pod number per plant in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation (The same letter (s) on the bars indicate non-significant different at $p < 0.05$).

NPS ha^{-1} combined with 10 t CM ha^{-1} and 300 kg NPS ha^{-1} combined with 10 t CM ha^{-1}. In contrast, the shortest (6.5 cm) and narrowest (1.60 cm) pod and the lowest (84.10) seed numbers per pod were obtained from the unfertilized plot, which were statistically similar to the pod length, width, and seed numbers per pod obtained at the plots receiving 5 t CM ha^{-1}, 100 kg NPS ha^{-1}, and 100 kg NPS ha^{-1} and 5 t CM ha^{-1}, respectively (Figs. 2–4). Overall, hot pepper pod length, width, and seed numbers per pod showed an increasing trend with the sole and combined application of NPS fertilizer and CM at an increasing level over an unfertilized plot, but further increments of NPS fertilizer along with the highest CM level showed a slight decrease in these three traits.

3.3.3. Marketable dry pod yield per hectare

Marketable hot pepper dry pod yield per hectare was significantly influenced by the main and interaction effects of NPS fertilizer and CM (Table 2). The result showed that as NPS fertilizer and CM levels increased, the marketable dry pod yield per hectare significantly increased at a certain limit; however, as the NPS fertilizer level increased further along with CM, the marketable pod yield per hectare decreased. The plot fertilized with a combination of 200 kg NPS ha^{-1} and 15 t CM ha^{-1} produced the highest (2.90 t ha^{-1}) marketable dry pod yield per hectare, which was statistically similar to the marketable dry pod produced from the plots fertilized with 10 t CM ha^{-1}combined with 200 and 300 kg NPS ha^{-1}. Conversely, the unfertilized plot produced the lowest (1.23 t ha^{-1}) marketable dry pod yield per hectare, and it showed statistically non-significant differences with the plot, which received 100 kg NPS ha^{-1} (Fig. 5). The combined application of 200 kg ha^{-1} NPS with 15 t ha^{-1} increased the marketable dry pod yield of hot pepper by 57.58 % compared to the unfertilized plot.

3.3.4. Unmarketable dry pod yield per hectare

The ANOVA result showed that NPS fertilizer, CM, and their interaction significantly affected the hot pepper unmarketable dry pod yield per hectare (Table 2). The plot fertilized with a combination of 200 kg NPS ha^{-1} and 10 t CM ha^{-1} produced the smallest (0.05 t ha^{-1}) unmarketable dry pod yield per hectare, and it showed a statistically similar result to the plot fertilized with the same level of NPS fertilizer combined with 15 t CM ha^{-1}. On the other hand, the unfertilized plot produced the highest (0.40 t ha^{-1}) unmarketable dry pod yield per hectare, which was statistically similar to plots fertilized with 100–300 kg NPS ha^{-1} and 5 and 10 t CM ha^{-1} (Fig. 6).

3.3.5. Total dry pod yield per hectare

The main and interaction effects of NPS fertilizer and CM had a significant effect on hot pepper total dry pod yield per hectare (Table 2). The highest (2.99 t ha^{-1}) total dry pod yield per hectare was obtained from the combined application of 200 kg NPS ha^{-1} and 15 t CM ha^{-1}, which was statistically par with the combined applications of 200 kg NPS ha^{-1} and 10 t CM ha^{-1}, 300 kg NPS ha^{-1} and 10 t CM ha^{-1}, and 300 kg NPS ha^{-1} and 15 t CM ha^{-1}. While the lowest (1.63 t ha^{-1}) total dry pod yield per hectare was obtained from the unfertilized plot, there was no significant difference between the total dry pod yields per hectare produced from the plot fertilized with 100 kg NPS ha^{-1} (Fig. 7). Total dry pod yield obtained from the application of 200 kg ha^{-1} NPS with 15 t ha^{-1} CM increased by 45.48 % as compared to the unfertilized plot.

3.4. Association of phenology, growth, and yield-related traits with hot pepper dry pod yield

The correlation analysis showed that days to flowering, pod setting, days to maturity, plant height, primary and secondary branch numbers per plant, pod numbers per plant, pod length and width and seed number per pod all had highly significantly and positively correlated with hot pepper marketable and total dry pod yield. On the other hand, unmarketable hot pepper dry pod yield was highly

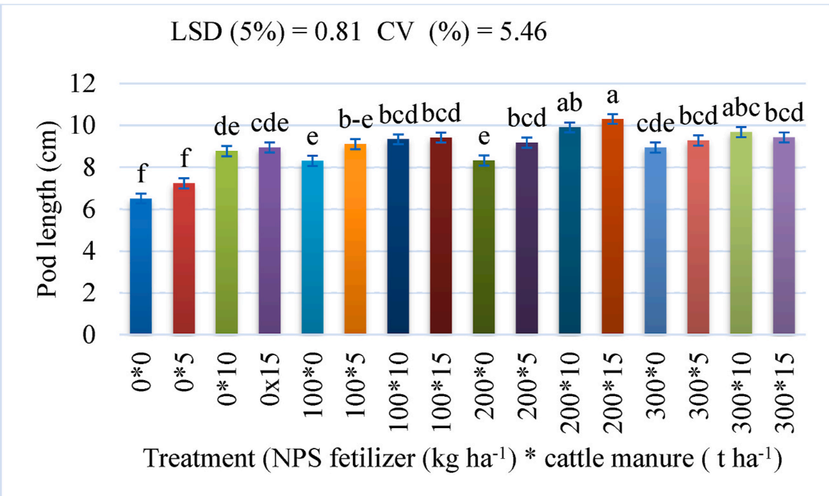

Fig. 2. Interaction effect of NPS fertilizer and CM on hot pepper pod length in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation (The same letter (s) on the bars indicate non-significant different at $p < 0.05$).

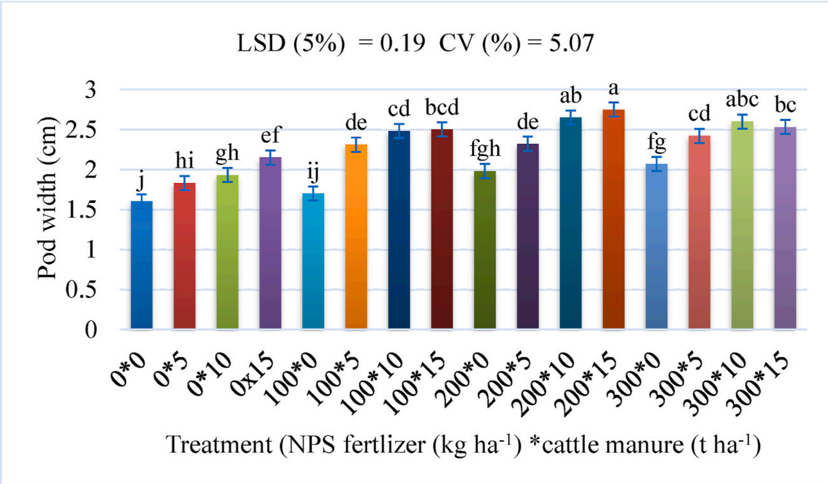

Fig. 3. Interaction effect of NPS fertilizer and CM on hot pepper pod width in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation (The same letter (s) on the bars indicate non-significant different at $p < 0.05$).

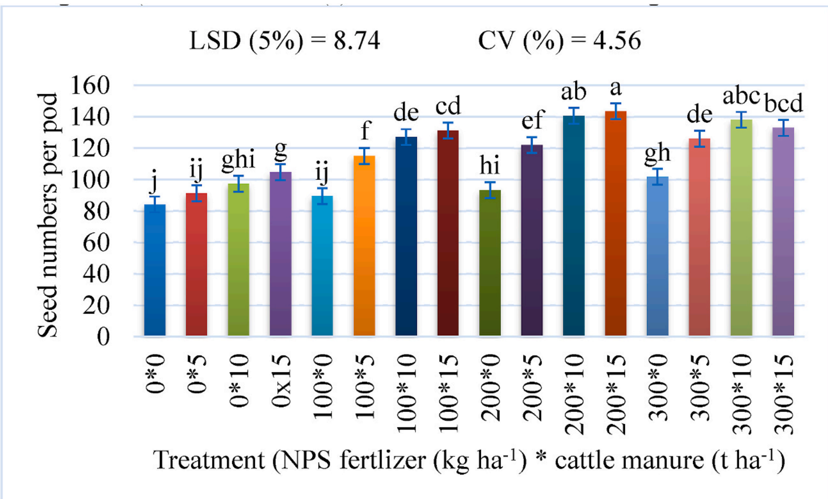

Fig. 4. Interaction effect of NPS fertilizer and CM on hot pepper seed numbers per pod in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation (The same letter (s) on the bars indicate non-significant different at $p < 0.05$).

significantly and negatively correlated with hot pepper phonology, growth, and yield-related traits (Table 6).

3.5. Partial budget analysis

The net benefit was calculated by determining the variable costs of the NPS fertilizer at 15.60 Ethiopian birr (ETB) kg^{-1}, CM at 550 ETB t^{-1}, and 100 ETB per person in a day to invest in labor costs for the application of the two fertilizers. Farmer sold the hot pepper dry pod at a price of 240 ETB kg^{-1} in 2021. The economic analysis demonstrated that the highest net benefit of hot pepper dry pod per hectare was recorded in the plot fertilized by the combination of 200 kg NPS ha^{-1} and 10 t CM ha^{-1}. However, the lowest net benefit per hectare was obtained from the unfertilized plot. The plot supplied at 200 kg NPS ha^{-1} had the highest MRR, followed by the combination of 100 kg NPS ha^{-1} and 5 t CM ha^{-1} and 200 kg NPS ha^{-1} and 10 t CM ha^{-1} (Table 7).

4. Discussion

The combined application of inorganic fertilizer and organic manure is a crucial soil fertility management strategy to improve soil fertility and sustain crop production [33,58]. The combined application of inorganic fertilizers and organic manure improves the overall physicochemical properties and fertility of agricultural soil by enhancing soil microbial diversity, activities and biomass, soil

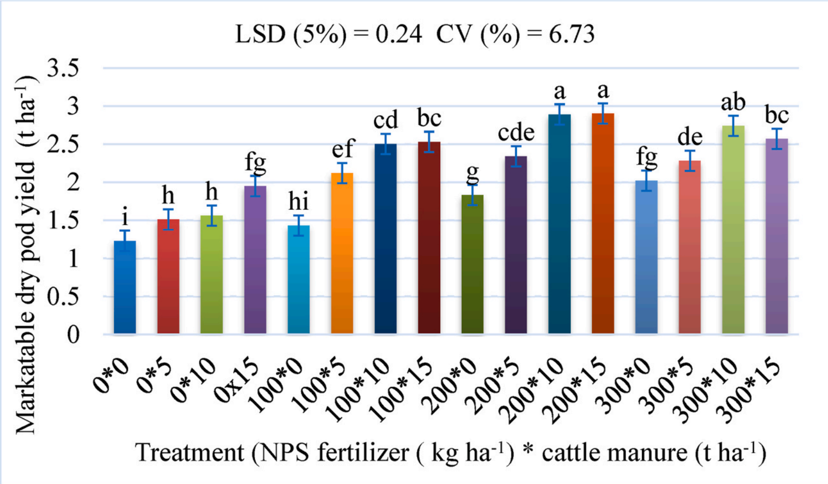

Fig. 5. Interaction effect of NPS fertilizer and CM on hot pepper marketable dry pod yield per hectare in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation (The same letter (s) on the bars indicate no significant different at $p < 0.05$).

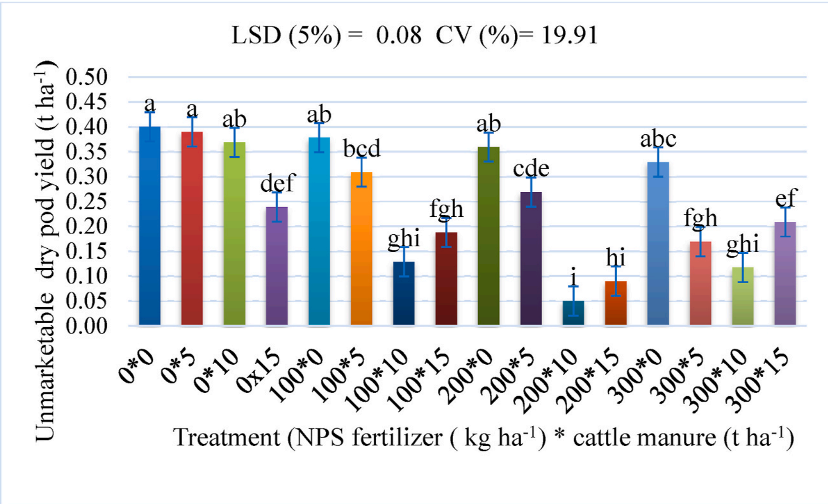

Fig. 6. Interaction effect of NPS fertilizer and CM on hot pepper unmarketable dry pod yield per hectare in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation (The same letter (s) on the bars indicate non-significant different at $p < 0.05$.

organic matter, soil structure and aggregation, soil water retention capacity, and soil health [59,60]. Combining inorganic fertilizers with organic manure also enhances healthy crop growth and productivity by improving crop nutrient use efficiency and providing balanced macro- and micronutrients to plants [61]. Numerous studies have demonstrated that applying inorganic fertilizers along with organic manure enhances and maintains soil fertility and crop production over applying inorganic fertilizers or organic manure alone [58,62]. Similarly, the current investigation showed that the application of NPS fertilizer and CM significantly modified soil chemical properties, such as OC, OM, pH, TN, AP, and CEC, and affected hot pepper phenology, growth, yield and yield-related traits. As shown in the results section, soil chemical properties and hot pepper phenology, growth, yield, and yield-related traits were significantly increased in the combined application of NPS and CM fertilizers compared to the sole application of the two fertilizers and the un-fertilized plot.

The combined application of NPS fertilizer and CM significantly enhanced soil OC, OM, and nutrient content compared to the sole application of the two fertilizers and the unfertilized plot in this study. The significant enhancement of OC and OM in the soil in this study through the combined application of NPS fertilizer and CM may be linked to the beneficial impact of CM application as a source of organic matter in conjunction with NPS fertilizer. Soil OC and OM are improved due to direct carbon and organic materials from CM and indirect carbon from residual crop biomass returning to the soil [58], hence the crop grows vigorously due to the combination of NPS and CM fertilizers. Moreover, CM boosts soil microbial biomass and the ability of their activity in the soil to enhance soil OC and OM [59,60]. Soil microbial activities and their biomass in the soil are critical to improving soil aggregation, encouraging carbon

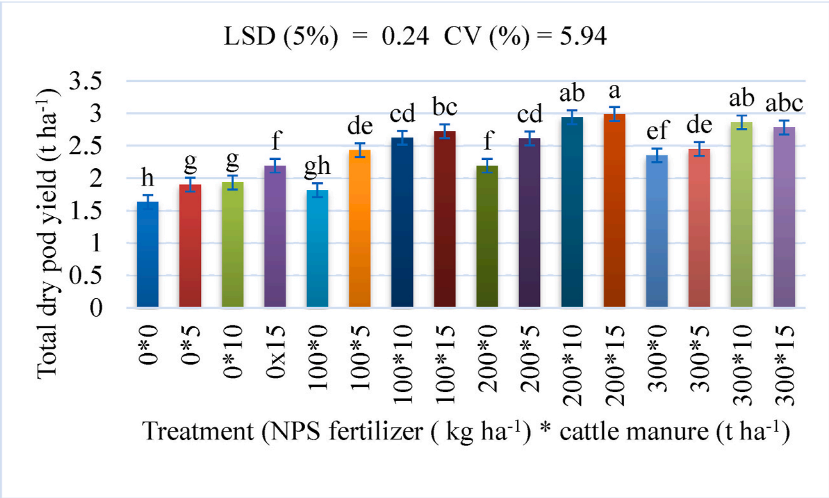

Fig. 7. Interaction effect of NPS fertilizer and CM on hot pepper total dry pod yield per hectare in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation (The same letter (s) on the bars indicate no significant different at $p < 0.05$.

Table 6
Correlation coefficient between hot pepper phenology, growth, and yield-related traits with hot pepper dry pod yield in Jabi Tehnan district, Ethiopia in 2020/21 under irrigation.

Traits	DF	DPS	DM	PH	NPB	NSB	NPPP	PL	PW	MPY	UPY	TPY
DPS	0.90[a]											
DM	0.93[a]	0.91[a]										
PH	0.86[a]	0.80[a]	0.87[a]									
NPB	0.78[a]	0.78[a]	0.81[a]	0.75[a]								
NSB	0.62[a]	0.63[a]	0.67[a]	0.59[a]	0.78[a]							
NPPP	0.89[a]	0.89[a]	0.89[a]	0.84[a]	0.76[a]	0.58[a]						
PL	0.76[a]	0.76[a]	0.76[a]	0.72[a]	0.75[a]	0.71[a]	0.75[a]					
PW	0.85[a]	0.85[a]	0.85[a]	0.89[a]	0.79[a]	0.64[a]	0.80[a]	0.83[a]				
MPY	0.89[a]	0.87[a]	0.87[a]	0.89[a]	0.79[a]	0.68[a]	0.86[a]	0.79[a]	0.91[a]			
UPY	−0.79[a]	−0.82[a]	−0.82[a]	−0.78[a]	−0.71[a]	−0.67[a]	−0.78[a]	−0.71[a]	−0.80[a]	−0.87[a]		
TPY	0.87[a]	0.85[a]	0.85[a]	0.88[a]	0.78[a]	0.65[a]	0.84[a]	0.78[a]	0.90[a]	0.99[a]	−0.79[a]	
NSPP	0.88[a]	0.90[a]	0.90[a]	0.92[a]	0.75[a]	0.63[a]	0.90[a]	0.75[a]	0.88[a]	0.94[a]	−0.85[a]	0.92[a]

DM, days to 90 % maturity; PH, plant height; NPB, number of primary branches; NSB, number of secondary branches; NPPP, number of pods per plant; PL, pod length; PW, pod width; MPY, marketable dry pod yield; UMPY, unmarketable dry pod yield; TPY, total dry pod yield; NSPP, number of seed per pod.

[a] , significant at $p < 0.01$; DF, days to 50 % flowering; DPS, days to 50 % pod setting.

turnover, and recycling N in the soil [63,64]. In the present study, as indicated in the results section, the increase in TN and AP in the soil could perhaps be attributed to the fact that CM reduced nutrient leaching through enhanced soil water retention, improved soil aggregation and structure, and the residual effect of both NPS and CM fertilizers in the soil [65,66]. Furthermore, besides the residual effects of NPS and CM fertilizers, applying CM directly to the soil enhances the soil's capacity to retain nutrients, reduces N leaching, and elevates N and P levels in the top soil [67]. Similar to this, soil scientists have verified that a combination of inorganic fertilizers with organic manures enhanced soil nutrient status along with improving soil physical and chemical properties due to the direct delivery of balanced macro and micronutrients and increased soil microbial activity and biomass in the soil [65]. Furthermore, a combination of inorganic and organic manure fertilizers is more effective to maintain and improve soil fertility and crop productivity simultaneously than applying only inorganic or organic manure fertilizers [62,68]. The current results are consistent with the findings of [69], who showed that applying NPSB fertilizer and chicken manure in combination with increasing levels enhanced soil OC, OM, TN, and AP over the control treatment and sole application of the two fertilizers. Correspondingly [70], found that the soil AP was improved due to the sole and combined application of NPSB fertilizer and CM at an increasing level over the control treatment. Additionally [58], who reported that the combination application of 40 % inorganic N fertilizer and 60 % poultry manure significantly improved soil OC, OM, TN, and AP over the control treatment. Moreover [71], reported that the combined application of 100 kg NPSZnB ha^{-1} and 4 t FYM ha^{-1} fertilizers significantly improved soil OC, OM, TN and AP compared to the control treatment in East Wollega, Ethiopia.

The combined application of NPS and CM fertilizers also significantly raised soil pH and CEC compared to the unfertilized plot in the current study. This might be due to the alkalinity of CM, which leads to modified soil pH and CEC [72]. Besides, CM applied alone

Table 7
Partial budget analysis results of hot pepper as affected by blended NPS fertilizer and cattle manure in Jabi Tehnan district, Ethiopia in 2021 under irritation.

NPS (kg ha^{-1}) * CM (t ha^{-1})	UAMPY (t ha-1)	AMPY (t ha^{-1})	GB (ETB ha^{-1})	Cost of fertilizer		Application cost (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	DA	Marginal rate of return (%)
				NPS	CM					
0*0	1.23	1.107	265680	0	0	0	0	265680		
0*5	1.51	1.359	326160	0	2750	150	2900	323260		1316.39
0*10	1.56	1.404	336960	0	5500	300	5800	331160	D	
0*15	1.95	1.755	421200	0	8250	450	8700	412500	D	
100*0	1.43	1.287	308880	1560	0	120	1680	307200		2471.43
100*5	2.12	1.908	457920	1560	2750	270	4580	453340		5034.43
100*10	2.5	2.25	540000	1560	5500	420	7480	532520		2732.79
100*15	2.53	2.277	546480	1560	8250	570	10380	536100	D	
200*0	1.83	1.647	395280	3120	0	240	3360	391920		14926.09
200*5	2.34	2.106	505440	3120	2750	390	6260	499180		2728.57
200*10	2.89	2.601	624240	3120	5500	540	9160	615080		4914.29
200*15	2.9	2.61	626400	3120	8250	690	12060	614340	D	
300*0	2.02	1.818	436320	4680	0	360	5040	431280	D	
300*5	2.28	2.052	492480	4680	2750	510	7940	484540	D	
300*10	2.74	2.466	591840	4680	5500	660	10840	581000	D	
300*15	2.57	2.313	555120	4680	8250	810	13740	541380	D	

CM, cattle manure; UAMPY, un adjusted marketable dry pod yield; AMPY, adjusted marketable dry pod yield; GB, gross benefit; TVC, total variable cost; NB, net benefit; DA, dominance analysis; D, Dominated; ETB, Ethiopian birr.

markedly increased the pH of the soil compared to the unfertilized plot and NPS fertilized plots. This could be because CM contains enough carbonate ions and basic cations to counteract soil acidification [73]. On the other hand, the sole application of NPS fertilizer at an increasing level lowered soil pH in comparison to an unfertilized plot. This could be because protons can be produced by mineral N nitrification due to the application of mineral NPS fertilizer, which lowers the soil pH [72]. In addition, excessive application of inorganic fertilizers like NPS without organic manure lowers soil pH and soil microbial biomass, which leads to increased soil acidification and reduced soil fertility [34]. This result is consistent with the finding of [69], who showed that the application of NPSB fertilizer coupled with chicken manure and chicken manure alone improved soil pH over the sole application of NPSB fertilizer. Similarly [58], reported that N fertilizer was applied in combination with poultry manure, and CM increased soil pH and CEC, but N fertilizer was applied alone, which decreased soil pH over the control treatment. Contrary to the current result [71], reported that the combined application of NPSZnB and FYM fertilizers at increasing levels decreased soil pH compared to the control treatment and the separate application of the two fertilizers in East Wollega, Ethiopia.

As reported in the results section, the application of NPS fertilizer and CM in the current study had a substantial effect on hot pepper flowering, pod setting, and maturity. In comparison to the unfertilized plot, hot pepper flowering, pod setting, and maturity were all delayed in both the sole and combination applications of NPS fertilizer and CM at increasing levels. This is due to the high levels of NPS and CM fertilizers, which may aid in the plant's uptake of rich nutrients and encourage the hot pepper's vegetative growth while postponing its flowering, pod setting, and maturity. Particularly in this study, when compared to the unfertilized plot, the combined application at the maximum level of NPS and CM fertilizers (300 kg NPS ha^{-1} and 15 t CM ha^{-1}) postponed the days to hot pepper flowering, pod setting, and maturity by 13, 22, and 26, respectively. This may be due to the fact that the plants received a high N level in the collaboration of NPS and CM fertilizers at the early and late growth stages, respectively, which promoted hot pepper vegetative growth and prolonged its flowering, pod setting, and maturity. Hence, inorganic fertilizer typically releases nutrients, particularly nitrogen, more quickly and supplies them to plants at an earlier growth stage, whereas organic manure releases nutrient slowly and provides them continuously throughout the growth season [74,75]. Furthermore, a high-level combination of NPS and CM fertilizers led to improved soil structure and enhanced plant nutrient availability, mainly N, which enhanced hot pepper vegetative growth and extended its reproductive phase and pod maturity [24]. According to Ref. [76] excessive N levels available to plants induce the plant to delay its reproductive phase by promoting vegetative growth and development. The current results are consistent with [11], who reported that the combination application of 300 kg NPS ha^{-1} and 10 t FYM ha^{-1} significantly extended the number of days to hot pepper flowering and pod maturity compared to the control treatment in western Ethiopia. Similarly [71], who reported that the combined application of 100 kg NPSZnB ha^{-1} and 4 t FYM ha^{-1} levels of fertilizer significantly prolonged hot pepper flowering and pod maturity compared to the unfertilized plot. In the same way as the current results [6], also reported that higher-level application of N-source fertilizers delays hot pepper flowering, pod setting, and maturity over control treatment. Moreover [17], reported that the plot that received higher levels of N and P fertilizers exhibited an extended period of hot pepper flowering and pod maturity relative to unfertilized plot.

Soil fertility is one of the factors that affects plant growth and growth-related traits, and optimum balanced soil fertilization has a significant positive effect on improving plant growth and growth-related traits [77–79]. In the present study, also hot pepper plant growth and growth-related traits such as plant height and the number of primary and secondary branches per plant were significantly affected and improved by the sole and combined application of NPS and CM fertilizers over the control treatment. However, compared to the sole application of NPS and CM fertilizers, combined applications of NPS and CM fertilizers increase plant height and the number of primary and secondary branches per plant at an increasing level. Moreover, in this study, the combination of 300 kg NPS ha^{-1} and 15 t CM ha^{-1} increased the plant height, primary and secondary branch numbers per plant by 43 %, 57 % and 66.27 %, respectively, compared to the unfertilized plot. This might be due to the sustained availability of N, P, and S to plants from the combined application of a high level of NPS and CM fertilizers. Hence, the combined effects of N, P, and S significantly improve continuous plant growth by increasing the synthesis of chlorophyll and building blocks of protein and improving photosynthesis [80,81]. The combination of NPS fertilizer with CM also improves plant growth traits by modifying the soil's CEC, OC, fertility, moisture retention, physicochemical composition, and enhanced plant nutrient use efficacy [82]. Furthermore, the combined application of NPS and CM fertilizers in the present study significantly enhanced plant growth and related traits compared to the sole application of the two fertilizers because it sustained soil fertility and enhanced nutrient uptake to the plant at early stage and steady throughout the growth season, respectively. Consequently, NPS fertilizer facilitates early-stage plant growth by allowing for quicker and easier nutrient intake to the plant due to its easily available and faster nutrients release, and CM continues plant growth by supplying nutrients gradually throughout the growth period, prolonging the senescence of leaves to enhance photosynthesis and promoting plant growth. The current results are consistent with [24], who reported that the combined application of 41 kg N ha^{-1}, 46 kg P ha^{-1}, and 5 t FYM ha^{-1} increased hot pepper plant height, primary and secondary branches per plant by 52.17 %, 77.5 %, and 43.83 %, respectively, compared to the control treatment. Likewise [83], also reported that combined and sole application of NPSZnB and FYM fertilizers increased hot pepper plant height and primary branches per pant over control treatment in East Wollega, Ethiopia. The authors also conclude that the combination of 100 kg NPSZnB ha^{-1} and 4 t FYM ha^{-1} enhanced plant height and primary branches per plant by 35.88 % and 57.03 %, respectively, in comparison to the control treatment. A similar result was also stated by Ref. [11], who reported that the sole and combined application of NPS fertilizer and FMY significantly affected hot pepper growth, and the combination of 200 kg NPS ha^{-1} and 5 t FYM ha^{-1} increased plant height over the control and other treatments. Similar to the current results [84], also reported that the highest branch numbers per chili pepper plant were recorded at the highest level of NPK fertilizer application over control treatment. Furthermore [85], reported that the application of the highest level of poultry manure produced the highest hot pepper branch numbers per plant compared to unfertilized plot.

As plants growth and development, crop yield, and yield-related traits are also significantly improved due to optimum soil fertilization [36,86,87]. Furthermore, as indicated in the result section, the result of this study indicated that hot pepper yield and yield-related traits were significantly affected by the application of NPS and CM fertilizers. The combined application of NPS and CM fertilizers resulted in higher pod number per plant, pod length, pod width, seed number per pod, marketable and total dry pod yield, and lower unmarketable dry pod yield when compared to the control treatment and the sole application of NPS and CM fertilizers. This may be because the combined application of NPS and CM fertilizers in this study improved soil fertility, which in turn enhanced nutrient uptake and leaf photosynthetic capacity by supplying enough macro- and micronutrients from NPS and CM fertilizers throughout the growth period. Particularly, the combined application of 200 kg NPS ha^{-1} and 15 t CM ha^{-1} significantly increased most hot pepper yield-related traits, marketable, and total dry pod yields compared to the other treatment combinations in the current study. On the other hand, the combination of 15 t CM ha^{-1} with NPS fertilizer beyond 200 kg NPS ha^{-1} exhibited a decreasing trend in marketable and total hot pepper dry pod yield compared to the combination application of 200 kg NPS ha^{-1} and 15 t CM ha^{-1}. This can be the result of plant nutrients being overly available to the plant, which could have a detrimental effect on pod production. Therefore, the combination of 200 kg NPS ha^{-1} and 15 t CM ha^{-1} is optimum for normal hot pepper growth and development and dry pod production in the study area. The current results are similar to those of [11], who reported that both sole and combined application of 100 kg NPS ha^{-1} and 5 t FYM ha^{-1} fertilizers increased marketable and total hot pepper dry pod yield in Dambi Dollo Ethiopia over unfertilized treatment. Similarly [88], reported that both the sole and combined application of NPS and CM fertilizer increased marketable and total hot pepper dry pod yield, and the combined application of 150 kg of NPS ha^{-1} and 7.5 t of CM ha^{-1} increased marketable dry pod yield by 54.76 % over unfertilized plot. Besides [24], reported that the combined application of 41 kg N ha^{-1}, 46 kg P ha^{-1}, and 5 t FYM ha^{-1} produced the highest pod numbers per plant, pod length and width, marketable, and total dry pod yield in Raya Azebo, Ethiopia. Similar results had also been reported by Ref. [83]: the combined application of 100 kg NPSZnB $ha^{-1}$and 4 t FYM ha^{-1} significantly increased hot pepper pod length and marketable and total dry pod yield by 37.94 %, 51.71 %, and 49.18 %, respectively, over the control treatment in East Wollega, Ethiopia. Furthermore [89], reported that the application of 50 % urea and 50 % FYM increased hot pepper pod yield by 40.35 % compared to the control treatment.

The analysis of correlation results in the current study revealed that hot pepper days to flowering, pod setting, and maturity, plant height, primary and secondary branch numbers per plant, pod numbers per plant, pod length and width, and seed numbers per pod had a highly significant and positive correlation with marketable and total dry pod yield. The significant and positive correlations of these traits with yield indicated that improved growth and yield-related traits had a positive direct impact on the improvement of hot pepper dry pod yield [90]. Furthermore, the significant and positive correlation of hot pepper days to flowering, pod setting, and pod maturity indicated that extended days to flowering, pod setting, and maturity lead to improved dry pod yield by promoting plant vigor growth, greenness, photosynthetic efficiency, and biomass accumulation. Longer growing seasons also enable plants to make better use of the resources available for plant growth, leading to an improved final yield. This suggestion is supported by Ref. [91], who stated that a prolonged vegetable growth period and delayed flowering and maturity lead to increased crop yield. Therefore, the application of NPS fertilizer and CM is important for extending the hot pepper growing period and improving growth and yield-related traits to increase dry pod yield. The current result is supported by Ref. [92], who reported that hot pepper days to 50 % flowering and pod maturity, primary branch per plant, fruit length, and fruit number per plant were highly significant and positively correlated with dry pod yield. Likewise [93], also reported that hot pepper seed numbers per pod, fruit length, and width had a significant and positive correlation with green and dry pod yield. The current result is inconsistent with [94], who reported that chill pepper days to 50 % flowering, pod setting, and maturity were inversely correlated with dry pod yield. This is perhaps a result of crop genetic variation and the use of NPS and CM fertilizers in the current study.

A partial budget analysis in the present study was done to know the exact rate of return that the farmers gain from their investment by changing the existing cultural practices with the new alternative practices, and it was expressed in percent. The non-dominated treatments were shown through their dominance over others in the sense that the treatment had a higher net benefit with the same or lower level of variable costs. The MRR of the seven non-dominated NPS fertilizers and CM was used to determine the relative profitability of the promising treatments. According to the partial budget analysis result, the highest net benefit of 615,080 ETB ha^{-1} was recorded from the combination of 200 kg NPS ha^{-1} and 10 t CM ha^{-1}. According to Ref. [57], the minimum acceptable MRR for farmers is 100 %. Therefore, the MRR attained at the combination of 200 kg NPS ha^{-1} and 10 t CM ha^{-1} was above the minimum acceptable MRR. The combination of 200 kg NPSha^{-1} and 10 t CM ha^{-1} had a higher (2.89 t ha^{-1}) hot pepper dry pod yield with the highest net benefit of 615,080 ETB ha^{-1} with an acceptable MRR. Therefore, according to this result, farmers can anticipate receiving an additional 149.26 ETB ha^{-1} for every 1 ETB invested in the combined application of 200 kg NPS ha^{-1} and 10 t CM ha^{-1}. Therefore, the combed application of 200 kg NPS ha^{-1} and 10 t CM ha^{-1} was economically optimum and feasible for hot pepper dry pod production in the study area.

5. Conclusions

Results in the current study showed that the main and interaction effects of NPS fertilizer and CM significantly influenced soil chemical properties, hot pepper phenology, growth, yield, and yield-related traits. The combination of NPS fertilizer and CM significantly improved soil chemical properties, hot pepper phenology, growth, yield, and yield-related traits. Except for hot pepper phenology, growth traits, and pod numbers per plant, soil chemical properties after hot pepper was harvested and hot pepper yield and related traits showed a slightly decreasing trend at further increasing the combination levels of two fertilizers. The combination of 300 kg NPS ha^{-1} and 15 t CM ha^{-1} had the highest days for hot pepper flowering, pod setting, pod maturity, plant height, primary and secondary branch numbers per plant, and pod numbers per plant. The highest soil OC, OM, TN, and AP values were recorded in the combination of 200 kg NPS ha^{-1} and 15 t CM ha^{-1}. Similarly, the highest hot pepper pod length and width, seed number per pod, marketable, and total dry pod yield per hectare were produced in the combination of 200 kg NPS and 15 t CM ha^{-1}. Therefore combined applications of 200 kg NPS ha^{-1} and 15 t CM ha^{-1} increases the soil chemical properties, yield and yield related traits of hot pepper. However, according to the partial budget analysis result, a higher net benefit of 615,080 Ethiopian birr ha^{-1} with an acceptable MRR of 4914.29 % was obtained in the combination of 200 kg NPS ha^{-1} and 10 t CM ha^{-1} fertilizer levels. Therefore, it could be concluded that 200 kg NPS ha^{-1} plus 10 t CM ha^{-1} level fertilizer was economically feasible for hot pepper dry pod production and could be recommended for hot pepper dry pod producers in the study area. In general, the results of this study indicated that the combined applications of NPS and CM fertilizers improved some soil chemical properties and hot pepper productivity more than the sole application of the two fertilizers. Nevertheless, further research is required; hence, the research was done for one variety, season, and location. It has to be repeated with other hot pepper varieties in different locations across seasons to make a sound recommendation. In addition, further research is needed to fully realize the long-term impact of inorganic NPS fertilizer combined with CM on soil physicochemical properties, soil microbes, soil health, and sustainable soil fertility management in addition to crop productivity.

Data availability statement

Data will be available on request.

CRediT authorship contribution statement

Bekele Azmeraw Mossie: Validation, Supervision, Investigation, Formal analysis, Conceptualization. **Mekuria Bereded Sheferie:** Writing – review & editing, Data curation. **Tiegist Dejene Abebe:** Writing – original draft, Software. **Muhajer Kedir Abedalla:** Writing – review & editing, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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