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Progress of Soil Fertility and Soil Health Management Research for Arabica Coffee Production in Ethiopia

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Abstract: Soil degradation is one of Ethiopia's most severe concerns, contributing for the country's low coffee production. Researchers have been conducted by different organizations for the past five decades to ameliorate the challenges. The goal of this review was to summarize and document major research achievements recorded so far and recommend future research directions. As a result, mixing coffee pulp and husk in the composting pile with organic elements like farm yard manure and leguminous plants generates nutritionally high-quality compost in 45 days. In terms of increasing coffee yield, decomposed coffee husk (DCH) was found to be superior to *Sesbaniasesban* compost. Compost application rates of 5 to 10 tons ha^{-1} (2 to 4 kg tree^{-1} in dry weight base) and an equal proportion of soil incorporation and surface (50:50%) application techniques were found to be superior in increasing coffee yield. 50% recommended NP mineral fertilizer (RMF) (172 and 77 kg ha^{-1} NP, respectively) + 50% recommended (DCH (10 ton ha^{-1} or 4 kg tree^{-1} on a dry weight basis), 50% RMF + 75% DCH, and *Desmodium*spp (green manure crop) + RMF (172 and 63 kg ha^{-1} NP, respectively) significantly ($P \leq 0.05$) promote clean coffee yield at Agaro, Haru and Jimma, respectively. Forest soil or blends of top soils, compost and sand in 3:1:0 and 2:1:1 ratio, or organic manure and top soil mixture in 1:4, 2:4 and 3:4 ratios, produced strong and healthy coffee seedlings. A nursery pot amended with 750 mg P pot^{-1} (2.5 kg soil) and 2.31 g lime + 250 mg P pot^{-1} and 10 g lime + 800 mg P pot^{-1} produced released pure line and hybrid seedlings, respectively, with superior dry matter yield at Jimma. Similarly, at Haru, an application of 4 g pot^{-1} lime + 12.5 g pot^{-1} DCH and 18.75 g pot^{-1} DCH was a promising ameliorating management for acid soil for production of vigorous coffee seedlings for field planting. Future research should concentrate on evaluating other organic inputs and combined reclamation of lime-mineral fertilizer-compost, frequency of application, economic benefits, and long-term effects on soil physicochemical properties, coffee yield and bean quality, and establish cost effective soil fertility management in coffee-growing areas of the country. Furthermore, timely revision and calibration of mineral fertilizer recommendations made in the past with newly released coffee genotypes has become critical.

Keywords: Acid Soil, Arabica Coffee, Inorganic Fertilizer, Integrated Organic and Inorganic Fertilizer, Organic Fertilizer

1. Introduction

One of the most difficult problems in Ethiopia's coffee growing areas is declining soil fertility. The soils have been subjected to nutrient leaching over time, resulting in low organic matter content and the need for careful management to support good crop yields. However, 95% of Ethiopian coffee farmers do not use inorganic fertilizers, and those who do use them do so at levels far below the recommended rates [25]. As a result, the country's average productivity of the crop is very low, estimated at about 0.7 ton ha^{-1} green coffee bean [6], necessitating much more vigorous technological intervention in the sector [22, 25].

Coffee is a crop that requires a lot of nutrients. The crop removes more nutrients from the environment than other tree crops on an annual basis [31]. According to reports, producing a ton of Arabica coffee beans removes 135, 16 and 120 kg of N, P and Kfrom the soil [32]. The crop's nutrient requirements are met by the soil or organic and/or mineral fertilizers. Thus, one of the most important factors influencing coffee plant productivity is nutrient management [31, 32].

It is believed that the use of organic and/or inorganic fertilizer is required for increased crop yield and quality. Several research efforts have been made over the last five decades to recommend the best soil nutrient and soil health management technologies for improved coffee production in the country. As a result, the goal of this paper is to summarize and document previous soil fertility and soil health management research achievements, as well as to recommend future research directions for improved Arabica coffee production and productivity in Ethiopia.

2. Materials and Methods

Academic publications were searched using hard copies literature sources such as progress reports, proceedings, journals, and university thesis work obtained from various institutions such as the Ethiopian Institute of Agricultural Research, regional research institutes, and universities. Only publications dealing with advancements in soil fertility and soil health management research for improved Arabica coffee production in Ethiopia were chosen and grouped for review.

3. Results and Discussion

3.1. Organic Fertilizer Management Research

3.1.1. Composting of Coffee Processing By-Product

An experiment was carried out to determine the best combination of coffee pulp and organic sources, such as farmyard manure (FYM) and leguminous plant material (LM) (*Desmodium* spp.), to speed up the composting process and produce compost with a better nutritional composition. In this study, all treatment combinations included 10% topsoil as well as varying proportions of coffee pulp with FYM and LM. The investigation revealed that when compared to the control pile (coffee pulp pile without amendments), adding organic material to the composting pile accelerated the composting process and resulted in nutritionally superior compost in 45 days. Besides, C/N ratio of all piles decreased at the end of 49 days of composting, indicating mineralization of organic matter and adequate evolution of microbial composting process (Table 1). The C/N ratio is expected to attain minimum values when mineralization of organic matter is completed [5, 10]. Results from similar experiments accomplished elsewhere also emphasised the beneficial effects of organic accelerators in producing nationally superior quality compost within short maturity time [21].

At the Jima Agricultural Research Center (JARC), an attempt was also made to evaluate the composting of coffee pulp without the addition of additives and with the addition of additives such as N mineral fertilizer (1 kg urea per meter cub coffee pulp) and FYM (70% coffee pulp:20% FYM:10% top soil by volume). The results showed that leaving coffee pulp to degrade naturally (without additives) takes 6 to 8 months to stabilize the organic content. However, composting coffee pulp with FYM (70% coffee pulp:20% FYM:10% top soil by volume) created nutritionally superior compost and required three months to generate nice, crumbly, friable compost with a homogeneous texture (Figure 1). Furthermore, the application of coffee pulp compost boosted the growth performance of coffee seedlings grown in nursery beds, demonstrating that coffee compost is a desirable soil amendment and a viable material for compost and vigorous coffee seedlings production [13]. Despite the fact that piles with asmendments had higher N content at the end of the composting process, the N content was generally lower than the results reported by other authors [7, 23]. In terms of practicality, heaps rather than pits were recommended for the preparation of large quantities of compost from coffee pulp [24].

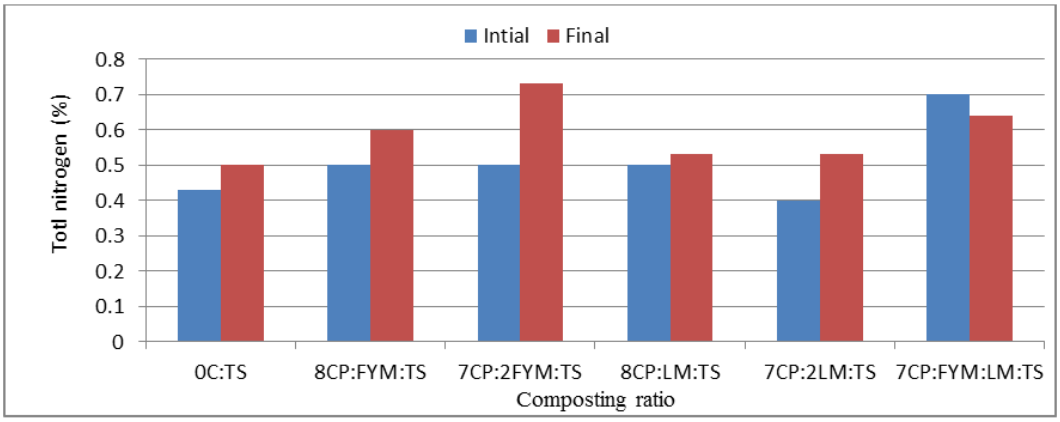

Figure 1. *Total nitrogen content of coffee pulp compost in the first and last weeks of composting. TS = Topsoil. Source: [17].*

In other study, it was reported that coffee pulp and husk chemical properties differed significantly before and after composting [7]. After composting, the pH, electrical conductivity (EC), cation exchange capacity (CEC), exchangeable K, Ca, and Mg and available Pof coffee husk increased, while organic carbon (OC), organic matter (OM), C:N ratio, and total N decreased (Table 2). Because of the element's high mobility, the decrease in K caused by composting coffee pulp is most likely due to leaching, which may also account for the decrease in CEC. [6] also reported that organic fertilizer improves the physicochemical properties of soil over time. In this regard, [8] found that using both non-composted and composted coffee processing byproducts improved soil physicochemical properties over time. In contrast, it has been reported that the incorporation of undecomposed or partially decomposed by-products with a relatively high C:N ratio may negatively impact production by causing N deficiency [5, 10, 32]. [31] also demonstrated that applying organic residues can improve soil physicochemical properties and increase fertilizer efficiency, resulting in a more favorable environment for plant growth and development.

Table 1. *Quality of coffee pulp compost in piles with different organic amendments and 10% top soil at the end of composting (49 days).*

Parameter	90% CP	80% CP + 10% FYM	70% CP + 20% FYM	80% CP + 10% LM	70% CP + 20% LM	70% CP + 10% FYM + 10% LM
Moisture (%)	38.23	30.89	36.97	28.48	36.12	34.59
pH	7.69	7.49	7.50	7.54	7.60	7.51
TN (%)	0.80	0.81	0.90	1.04	1.06	0.83
OC (%)	7.15	6.71	6.71	5.67	5.62	5.88
C/N ratio	8.5	8.3	7.5	5.5	5.3	7.1

TN = Total nitrogen, OC = Organic carbon, CP = Coffee pulp, LM =Leguminous plant material (Desmodium spp.) and FYM = Farm yard manure. Source: [24].

Table 2. *Composting effect on chemical properties of coffee pulp and husk.*

Chemical properties	Unit	Coffee husk		Coffee pulp	
		Uncomposted	Composted	Uncomposted	Composted
pH	pH scale	5.63	6.15	5.54	7.17
EC	mmho cm^{-1}	0.34	0.71	Trace	1.26
CEC	meq $100g^{-1}$	58.72	65.01	83.76	69.74
Exch. K	meq $100g^{-1}$	11.36	16.11	118.80	65.01
Exch. Ca	meq $100g^{-1}$	18.96	20.46	2.50	8.98
Exch. Mg	meq $100g^{-1}$	6.62	8.25	4.46	5.00
OC	%	38.78	21.15	33.84	14.21
OM	%	66.86	36.47	58.34	24.49
Total N	%	1.71	1.15	2.23	1.39
C:N ratio	ratio	22.68	18.39	15.17	10.22
Available P	ppm	33.14	63.46	89.42	96.88

Exch. = Exchangeable**.** Source: [7].

Table 3. *The impact of coffee processing byproducts on coffee growth and yield (kg ha-1) at the Gomma and Gummer farms in southwest Ethiopia.*

Treatment	Rate (t ha-1)	Location				Clean coffee yield (kg ha-1) (mean of 2 years)	
		Gomma II		Gummer			
		Height (cm)	Girth (mm)	Height (cm)	Girth (mm)	Gomma II	Gummer
C	0	33.7	11	19.0	10	412	252
NH_1	5	34.3	12	21.3	13	436	300
NH_2	10	38.0	14	27.0	14	465	352
NH_3	15	41.7	16	30.0	15	516	379
CH_1	5	34.0	14	24.3	14	495	315
CH_2	10	42.7	15	30.7	15	566	436
CH_3	15	44.3	17	32.0	17	623	417
NP_1	5	34.7	15	25.7	14	492	334
NP_2	10	39.0	17	29.7	14	510	322
NP_3	15	39.0	17	32.7	15	548	414
CP_1	5	35.0	14	26.3	13	543	400
CP_2	10	42.0	17	33.3	14	710	475
CP_3	15	43.3	18	34.0	18	605	433
NP	176/32	57.0	23	50.0	20	857	517
Mean		39.9	16	29.7	15	556	382
SE (±)		1.9	0.6	1.2	0.6	24	15
LSD (0.05)		3.8	1.2	2.5	1.2	47	30

C = Control, NH = Non-composted coffee husk, CH = Composted coffee husk, NP = Non-composted coffee pulp and CP = Composted coffee pulp. Source: *[8]*.

3.1.2. Response of Coffee Trees to Coffee By-Products and Farm Yard Manure

At Gummer and Gomma II farms in southwest Ethiopia, different rates of composted and uncomposted coffee pulp and husk were tested to see how they affected Arabica coffee growth and yield. The results showed that increasing the rate of coffee pulp and husk compost treatment increased the height, girth, and yield of coffee trees in a linear fashion. Plots amended with NP fertilizer outperformed control plots in terms of coffee tree height, girth, and yield, with the former having the highest and latter having the lowest (Table 3). In contrast, incorporating undecomposed or partially decomposed by-products with a high C:N ratio has been shown to reduce productivity by causing N deficiency.

At JARC, various organic amendments such as DCH, undecomposed coffee husk (UDCH), FYM, DCH + UDCH, recommended mineral fertilizer (172 and 63 kg ha^{-1} NP, respectively), and a control plot (without any soil amendment) were evaluated for their effect on coffee yield. The results showed that soil fertility amendments had a significant effect on coffee yield. As a result, the plots that received industrial fertilizer, DCH, FYM, UDCH, and DCH + UDCH in that order had the highest but statistically non-significant yield response. In contrast, the lowest clean coffee yield recorded from the control plot was significant (Table 4). In general, the findings support the use of locally available organic resources instead of chemical fertilizer to boost coffee production for the country. The effect of organic input, on the other hand, can vary depending on nutrient composition, rate of decomposition, amount and method of application, and climatic conditions in the area [28].

Table 4. *Mean yield (clean coffee kg ha^{-1}) as affected by soil fertility amendments at Jimma.*

Treatment	**Cropping year**					
	2004/05	**2005/06**	**2006/07**	**2007/08**	**2008/09**	**Mean**
	NS	**	**NS**	**	**NS**	*
DCH + UDCH	920	2679[a]	1133	1791[a]	570	1418[a]
DCH	1214	2644[a]	1605	1584[a]	960	1602[a]
UDCH	1120	2623[a]	1380	1433[a]	900	1491[a]
FYM	1046	2831[a]	1361	1779[a]	730	1550[a]
NP	1131	2686[a]	1568	2025[a]	1030	1689[a]
Control	966	2090[b]	1754	1087[b]	810	1342[b]
S.E (±)	116.00	137.30	177.60	125.50	270.0	81.90
CV (%)	32.7	15.90	36.3	23.3	97.2	44.7

NS = Non significant, * and ** =Significant at 5 and 1% probability level, respectively. Meanvalueswithin a column followed by the same letter(s) are not statistically significant at P = 0.05 probability level. Source: [18]

In an effort to evaluate the rate and application technique of organic fertilizer, JARC investigated two organic fertilizer sources, *Sesbaniasesban*and coffee by-product compost, and organic fertilizer application techniques, such as soil surface (SA) and soil incorporation (SI) at the ratios of 0:100, 50:50, and 100:0%, for their mineral values in promoting coffee yield. On a dry weight basis, the organic fertilizers were evaluated at rates of 0, 5, 10, 15, and 20 ton ha^{-1} (Table 5 and Figure 2). The findings revealed that coffee by-product compost outperformed *Sesbaniasesban* applied plots for all application rates in increasing Arabica coffee yield. At a rate of 10 ton ha^{-1} coffee by-product compost, the highest clean coffee yield was recorded (Figure 2). An over year analysis revealed that an equal proportion of surface application and soil incorporation of organic resources (50:50%) was superior to the other application techniques (Table 5). The findings were consistent with previous studies on the use of coffee processing byproducts and leguminous trees such as *Sesbaniasesban* (ICRAF, 1996).

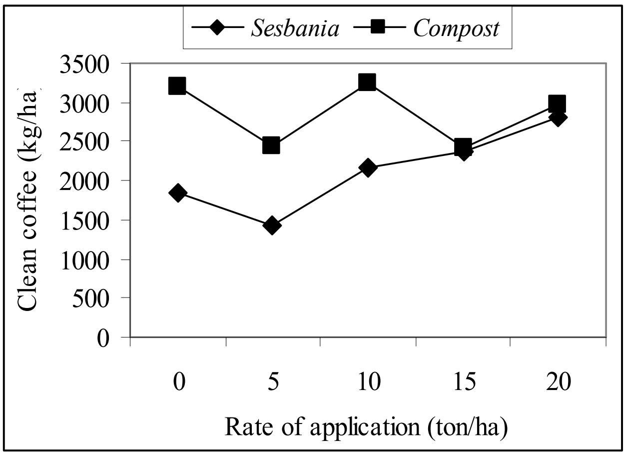

Figure 2. *Effect of organic fertilizer application rate on coffee yield (kg ha^{-1}) at Jimma. Source: [28].*

Table 5. *Mean yield (clean coffee kg ha^{-1}) as affected by organic fertilizer application techniques at Jimma.*

Application techniquesof organic fertilizer (SA:SI%)	**Cropping year**			**Mean**
	1999/2000	**2001/02**	**2003/04**	
	NS	NS	NS	NS
0:100	2040	4028	2361	2810
50:50	1846	4203	2606	2885
100:0	1699	4013	2504	2739
CV (%)	60.07	28.30	39.74	

NS = statistically not significant at P = 0.05 probability level. Source: Tayeet al. [28].

Coffee seedlings can be grown in raised beds (15 cm high) or in polythene tubes (10 -12 cm diameter and 22 cm high) filled with forest soil collected from the top 5 -10 cm depth. In the absence of forest soil (FS), it was suggested to use blends of top soil, compost and sand in various ratios following the order of 3:1:0 > 2:1:1 > 2:2:0 > 6:2:0 > 6:3:2 (Figure 3). [27] discovered that a mixture of locally available organic residue and topsoil in 1:4, 2:4, and 3:4 ratios stimulated both shoot and root growth in coffee seedlings. If this media blend is suspected of being deficient in plant nutrients, adding 2 g DAP per seedling or per pot after the seedling has two pairs of true leaves will improve seedling growth [2].

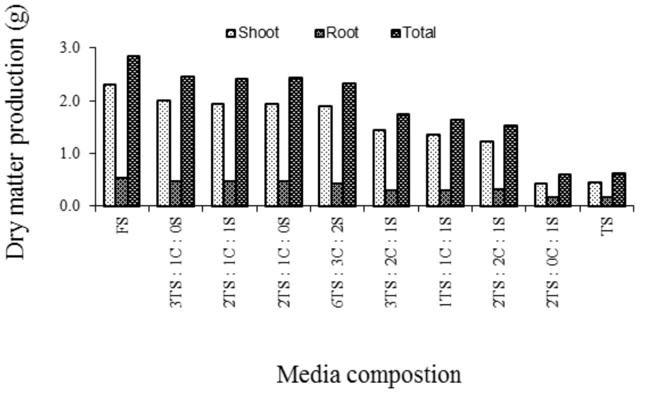

Figure 3. *Effect of different media composition on dry matter production of coffee seedlings. TS = Top soil. C = Compost and S = Sand. Source: [2, 3].*

3.2. Inorganic Fertilizer Management Research

3.2.1. Nitrogen and Potassium Mineral Fertilizer

Nitrogen is an essential plant nutrient that the coffee tree requires for vegetative growth. When compared to other nutrients, it is required in large quantities by the coffee plant (Wintgens, 2004). Furthermore, one of the most important nutrients for coffee production is K. It is required for coffee tree fruit development. The use of potassium fertilizer, on the other hand, is uncommon among Ethiopian farmers. This is due to the widely held belief that K is not a limiting nutrient in Ethiopian soils, a belief that is frequently based on the [14] report. In contrast, Ethiopian agriculture makes extensive use of potassium nutrients, which are extracted or mined from the soil [25, 26]. Coffee is also known to be a high feeder of Knutrient [32]. To address the issues, efforts have been made over the last five decades at JARC, including its sub-center and trial sites (Gera, Tepi, Haru, Metu, Bedessa, Agaro, Wonago, and Bebeka) to determine the optimum N and K fertilizer rate for coffee production, which represent different agro-ecologies of the country's coffee growing areas. Accordingly, Various N fertilizer trials were conducted at JARC and sub-centers and trial sites in order to determine the optimum N rate for coffee production. The response of coffee trees to N fertilizer application at Melko (Jimma) revealed that coffee yield increased significantly with increasing N level from 0 to 300 kg ha^{-1} but the most noticeable yield response of coffee was discovered at 150 kg ha^{-1}. An increase in the N rate level above 150 kg ha^{-1} did not have a significant effect on yield (Figure 4(a)). Similar trials in Gera, Metu, and Tepi (southwest Ethiopia) revealed no significant effect with increased N rate, whereas in Bedessa (West Harerghe, Ethiopia), though statistically not significant, a positive coffee yield response to fertilizer application was observed [16, 17]. However, a significant yield response of coffee to N fertilizer application was observed in Wonago (southern Ethiopia). The study area's optimal N rate was determined to be 200 kg ha^{-1} [11].

Potassium fertilizer trials also revealed positive crop responses to K application [15, 19]. In a fertilizer experiment at Melko, increasing the K level from zero to 62 kgha^{-1} resulted in a significant increase in coffee yield (Figure 4(b)), but increasing the K level further did not result in an increase in yield [15, 19]. A similar experiment at Gera, Metu, and Tepi, on the other hand, found no significant fertilizer effect on coffee yield [14, 15]. Since previous K level assessments of Ethiopian soils in general, and soils of the major coffee growing areas in particular, were completed a long time ago [12]. The issue of K fertilizer requirements in coffee must be addressed on the national research agenda. The data generated may have a significant impact on the country's fertilizer use in general, and the coffee industry in particular.

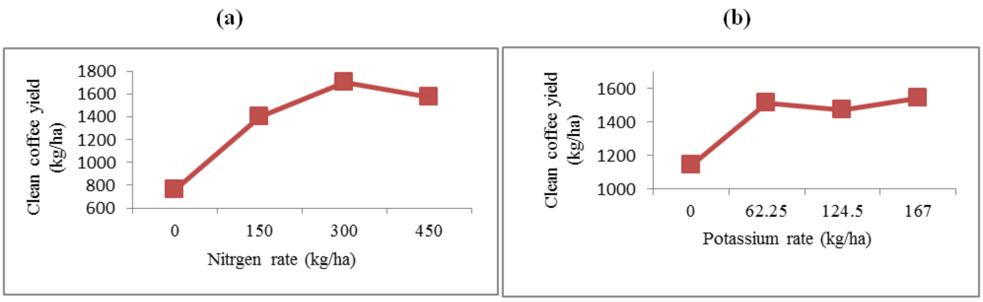

Figure 4. *Effect of N (a) and K (b) mineral fertilizer rate on yield of coffee at Jimma Source: [21].*

3.2.2. Phosphorus Mineral Fertilizer

Phosphorus is also known as a major nutrient in coffee production and is critical for flower bud, fruit and root development. However, it has been reported that phosphorus is one of the most widely recognized limiting nutrients for coffee production in most Ethiopian coffee-growing soils [25]. The soils are highly weathered, have a low pH, and high Fe and Al contents, resulting in high P fixation [22]. Results showed a 50% increase in coffee yield was reported in a field experiment at Jimma when the level of P was raised from 0 to 33 kg ha^{-1}, but further increases in the level of this nutrient did not result in increased yield at Jimma (Figure 5). Similarly, a significant yield response of coffee to P fertilizer application was observed at Wonago, with the result indicating that 66 kg ha-1 was the optimum P rate for the study area [12]. Similar experiments at Gera, Tepi, and Metu, on the other hand, yielded no significant yield response [14, 15].

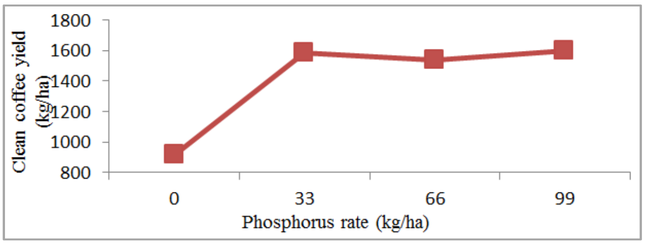

Figure 5. *Effect of P mineral fertilizer rate on yield of coffee at Jimma. Source: [21].*

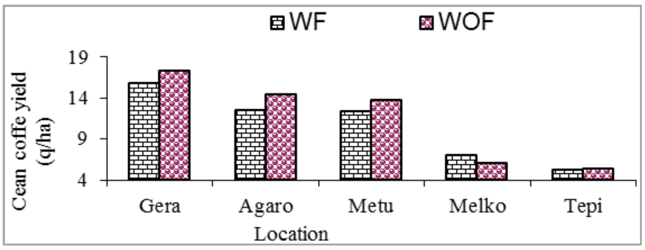

Figure 6. *The effect of mineral fertilizer application on forest coffee yield (four years mean). WF = With recommended mineral fertilizer rate (172 and 63 kg ha^{-1} NP, respectively, for Melko (Jimma) and 172 and 77 kg ha^{-1} NP, respectively, for the rest of study locations) and WOF = Without mineral fertilizer, WF = With mineral fertilizer and q = quintals, where 1q = 100kg. Source: [3].*

3.2.3. Phosphorus Horizontal and Depth Placement Method

Tesfu and Zebene (2004) conducted a coffee study at JARC to determine the optimum horizontal placement distance and depth of P placement. The results revealed that P placement distances and depth had a significant impact on the fresh and dry weights of coffee tree roots. Phosphorus applied at a horizontal distance of 45 cm from the main stem of the coffee seedling and at a vertical distance of 15 cm depth was discovered to be the optimum placement of P fertilizer for vigorous and healthy coffee tree growth. The highest available P content in the soil was discovered 80 days after application at a horizontal distance of 45 cm from the the makn stem of the tree and a vertical distance of 15 cm depth [29].

3.2.4. Phosphorus Status of Long-Term Fertilized Plots

At Jimma, an experiment was carried out to investigate the status of N, P, K, P, C and micronutrients (Fe, Mn, Zn and Cu) in response to inorganic fertilizer applications for many years in coffee-growing soils. Accrding to data in Table 6 long-term industrial fertilizer application resulted in P accumulation and a decrease in soil pH. The result therefore, confirmed the imbalance of nutrients caused by continuous application of mineral fertilizers. Such a build-up in P fertilizer results in imbalance of plant nutrients in the soil and makes it difficult for future fertilizer trials. As a result, P fertilizer studies must be conducted in areas where soil acidity and P levels are not prevalent [29].

Micronutrient levels, on the other hand, were found to be higher in long-term fertilized than in unfertilized soils, indicating that soil pH reduction improves solubility and thus availability of these micronutrients. Corrective measures should be pursued in long-term fertilized soils rather than emphasizing increased micronutrient availability, because no visible and critical micronutrient deficiency has been observed in the area thus far [8].

Table 6. *Long-term fertilizer application effect on soil fertility status at Jimma.*

Sites	PH	N (%)	P (ppm)	K (me/100g)	C (%)	CEC	DTPA- Soluble micronutrients (ppm)			
							Fe	Mn	Zn	Cu
1	6.0	6.0	0.18	7.2	0.93	1.8	32.8	148.2	2.8	3.2
2	5.2	5.2	0.22	23.8	1.13	2.7	58.1	124.5	3.3	3.7
3	4.8	4.8	0.21	15.8	0.53	2.8	46.5	131.5	2.3	3.7
4	4.9	4.9	0.21	24.1	0.50	2.5	49.8	155.9	2.7	3.1
5	5.5	5.5	0.27	36.6	1.08	3.0	52.8	101.8	2.9	3.1
6	4.7	4.7	0.22	82.4	0.71	3.9	63.2	219.1	5.5	4.5
7	5.5	5.5	0.21	65.3	0.66	3.5	61.9	131.9	3.0	2.7
8	6.1	6.1	0.22	40.6	0.89	3.5	68.4	172.6	3.3	4.2
9	5.7	5.7	0.22	3.6	0.67	3.6	32.4	157.2	1.9	3.2
10	6.1	6.1	0.18	2.8	0.78	3.3	48.9	109.1	2.1	3.3
S.E. (±)	0.17	0.17	0.01	8.06	0.10	0.2	12.1	34.1	1.1	0.6

Sites 1-8 was fertilized for 15 to 20 years, and sites 9-10 was unfertilized adjacent fields Source: [30].

3.2.5. Coffee Yield Response to NPK Mineral Fertilizer

At Gera, Agaro, Metu, Melko (Jimma) and Tepi, the response of forest coffee trees to applied NP mineral fertilizer was evaluated. The trial results showed that the application of inorganic fertilizer did not have a significant effect on forest coffee yield at the study locations (Figure 6). The lack of response of forest coffee trees to mineral fertilizer application could be attributed to high OM content of the soil as a result of mineralization of dense litter fall of shade trees, which masked, depressed, or nullified the effect of fertilizer on the performance of coffee trees beneath [3].

At Jimma, a separate experiment on hybrid coffee (Gawe) was conducted to assess the effect of NPK inorganic fertilizer rate on yield. The result revealed a statistically significant difference between treatments. Recommended NPK + 50% recommended NPK yielded the highest, most economically profitable, and most acceptable hybrid coffee yield in the Jimma area (Tables 7 and 8).

Table 7. *Clean coffee yield (kg ha^{-1}) of hybrid coffee as influenced by NPK mineral fertilizer rate at Jimma.*

Treatments	Cropping year					Mean
	2016	2017	2018	2019	2020	
Control	562.0^{c}	1147.5	1361.8	1385.7^{b}	925.5^{c}	1076.5^{c}
RRMFNPK	596.5^{cb}	1303.5	1702.0	1512.2^{ab}	1475.8^{b}	1318.0^{bc}
RRMFNPK + 25%RRMFNPK	947.7^{a}	1185.8	1359.4	1703.5^{ab}	1589.7^{b}	1357.2^{ba}
RRMFNPK + 50%ofRRMFNPK	912.9^{a}	1248.3	1502.9	2074.9^{a}	2232.0^{a}	1594.2^{a}
RRMFNP+ 25%ofRRMFNP	594.5^{cb}	1476.0	1374.3	1776.8^{ab}	1570.1^{b}	1358.3^{ba}
RRMFNP + 50%ofRRMFNP	676.3^{b}	1406.0	1454.3	1975.2^{ab}	1964.0^{ba}	1495.2b^{a}
LSD $_{(0.05)}$	111.9	NS	NS	643.96	495.37	274.99
CV (%)	10.40	31.50	43.42	24.58	20.08	13.35

RRMF = Recommended mineral fertilizer rate (172, 63 and 62 kg ha^{-1} NPK, respectively). Figures within a column followed by the same letter(s) are not statisticallysignificantly different from each other at P = 0.05 probability level. Source: [19]

Table 8. *Economic analysis of hybrid Arabica coffee yield response as influenced NPK mineral fertilizer rate at Jimma.*

Treatments	Adjusted yield (clan coffee, kg ha^{-1})	Total revenue (Birr ha^{-1})	Total variable cost (Birr ha^{-1})	Net benefit (Birr ha^{-1})	MRR (%)
Control	915.03	77,777.13	0	77,777.13	-
RRMF NPK	1120.30	95,225.50	12192.50	83,033.00	43
RRMF NPK+25%of RRMF NPK	1153.62	98,057.70	15240.63	82,817.07	D
RRMF PK + 50% ofRRMF NPK	1355.07	115,180.95	18288.75	96,892.20	461
RRMF NP+ 25% ofRRMF NP	1154.56	98,137.18	13665.63	84,471.55	D
RRMF NP +50%ofRRMF NP	1270.92	108,028.20	16398.75	91,629.45	261

RRMF = Recommended rate of mineral fertilizer (172, 63 and 62 kg ha^{-1} NPK, respectively). MRR= Marginal rate of return and D - Dominated. *Source: [19].*

3.2.6. Mineral Fertilizer Recommendations

Throughout the last five decades, extensive mineral fertilizer trials have been conducted at JARC and its sub-centers, which represent the country's key coffee growing agro-ecologies. As a result, it was possible to develop a set of mineral fertilizer recommendations, which are shown in Table 9. However, the recommended mineral fertilizer rate varies based on coffee production system, fertility of soil, soil pH, coffee genotypes, plant density and age of the coffee tree. As a result, open and lightly shaded coffee plantations, high-yielding genotypes, and mature trees on low fertile soil should receive the full dose of fertilizers. For wiled coffee, nutrient-rich soil, low yielding genotypes, and young trees (3 years old) should be given 2/3 of the recommended rate. However, for high populated trees (>4000 trees ha^{-1}) and high yielding trees, one and one-fourth of the recommended rate should be applied [16].

Table 9. *NPK mineral fertilizer recommendations fo coffee based on location.*

Location	Locations	Recommendationdmain (Kg ha^{-1})		
		N	P	K
Melko	Jimma, Manna, Seka, Gomma, and Kossa	150 - 172	63	0
Gera	Gera	No fertilizer	No fertilizer	No fertilizer
Metu	Metu, Hurumu, Yayou, and Chora	172	77	0
Tepi	Tepi	172	77	0
Bebeka	Bebeka	172	77	0
Wenago	Wonago, Dale, AletaWondo, and Fiseha Genet	170 - 200	33 - 77	0
Bedessa	Habro, Kuni, Darelebu	150 - 235	33 - 77	62

Source: [16].

3.2.7. Time and Method of Mineral Fertilizer Application

The most commonly used N, P and K industrial fertilizer sources for coffee is urea, DAP, TSP and KCl (Solomon *et al.*, 2008). It was recommended that N mineral fertilizer, urea, should be applied in March/April, June/July, and September, while P mineral fertilizer, DAP and TSP and K mineral fertilizer, KCland K_2SO_4, should be applied in March/April and September in the rainy season [16, 22]. Mineral fertilizer should be applied under the canopy of the tree but 20 cm far from the main stem of the tree. However, tominimize N loss mulch should be applied immediately after chemical fertilizer application.

3.2.8. Verification of the Recommended Mineral Fertilizer Rates

On-farm verification trials at Jimma to validate the recommended mineral fertilizer rates for coffee production revealed that the highest yield of coffee was obtained at recommended mineral fertilizer rate for the study location (172 and 63 kg ha^{-1} NP, respectively). Furthermore, coffee trees treated with 62 kg ha^{-1} K inorganic fertilizer yielded significantly more than the control and at 1/2 the recommended NP fertilizer rates (Table 10). According to the result, the recommended NP fertilizer rates produced the highest yields. Additionally, the use of K fertilizer resulted in higher coffee yields.

Table 10. *The effect of NP fertilizer treatments on coffee yield around Jimma.*

Treatments (kg ha^{-1})	Clean coffee yield (kg ha $^{-1}$)			Mean
	1996	1997	1998	
Control	1020	1152	942	1038
$N_{86.2}P_{31.5}$	977	1092	1235	1102
$N_{172}P_{63}$	1567	1372	2147	1695
K_{62}	1412	1237	1282	1311
LSD $_{(0.01)}$	403			
S.E. (±)	2.06			
CV (%)	27.77			

Source: [8].

3.3. Integrated Nutrient Management Research

Tegrated nutrient management is defined as "the intelligent use of the optimal combination of organic, inorganic, and biological nutrient sources in a specific cropping system to achieve and sustain maximum yield without harming the soil ecosystem [10]. A plant nutrient package of this type must be technically sound, economically viable, practically feasible, socially acceptable, and environmentally safe. In a nutshell, integrated nutrient management is a holistic approach that can be defined as "the maintenance of soil fertility and plant nutrient supply to an optimum level for maintaining crop productivity at the desired level" [10].

3.3.1. Integrated Use of Organic and Inorganic Fertilizer

Field experiments were conducted in Haru (west Wollega, Ethiopia) and Agaro (southwest Ethiopia) to evaluate the effect of integrated application of NP mineral fertilizer and in promoting coffee yield. The results showed that combining 50%recommended NP mineral fertilizer (RMF) (172 and 77 kg ha-1 NP, respectively) with 75% recommended DCH (10 ton ha^{-1} or 4 kg tree 1 on dry weight basis) and 50% RMF + 50% RDCH yielded significantly higher average yields of 1752.2 and 2083.5 kg ha^{-1} clean coffee at Haru and Agaro, respectively (Tables 11 and 12).

3.3.2. Integrated Use of Mineral Fertilizer and Green Manure Cover Crop

CBD resistant coffee cultivars (variety 74110) were treated with mineral fertilizer only and varying rates of inorganic fertilizer and Desmodium at JARC between 2016/17 and 2019/20 cropping years. For comparison, a control (no mineral fertilizer or *Desmodium*) was also included in the study. The results of a multi-year analysis of variance revealed that, while treatment effects were not statistically significant, plots that received *Desmodium* spp (green manure crop) + 50% RMF (172 and 63 kg ha^{-1} NP, respectively) and RMF received the highest clean coffee yield, bean quality, weed control efficiency, and net benefit (Tables 13 and 14 and Figure 7). In general the findings reveled that inorganic and green manure crops improves physicochemical properties of the soil as and thus creating more favorable conditions for plant growth and development [32].

Table 11. *The Effect of integrated nutrient management on yield (kg ha^{-1}) of coffee at Haru.*

Treatment	Yield (clean coffee kg/ha)				Over year
	2016/17	2017/18	2018/19	2019/20	mean
100% DCH	1264.4[ab]	770.1	2290.8	678.1	1250.85
100% NP	1410.3[a]	1097.9	2480.8	698.4	1421.85
100% NP+25% RDCH	1474.6	636.3	2934.1	790.2	1458.8
75% NP +50% RDCH	1594.1	767.8	3469.9	787.8	1654.9
50% NP +50% RDCH	1505.1	698.6	2699.8	771.0	1418.63
50% NP +75% RDCH	1442.	613.3	3960.7	991.9	1752.18
25% NP +75% RDCH	1431.1[a]	638.6	2364.7	816.2	1312.65
25% NP+100% RDCH	1213.6	620.1	2457.0	928.9	1304.9
Control	812.3	415	1155.5	480.7	715.88
CV (%)	20.4	38.4	19.3	19.1	
LSD (0.05)	477.4	462.5	883.6	255.2	285.2

RDCH = Recommended decomposed coffee husk (10 ton ha^{-1} or 4 kg tree^{-1} on dry weight base) and. *Source: [19].*

Table 12. *The Effect of integrated nutrient management on yield (kg ha^{-1}) of coffee atAgaro.*

Treatment	Yield (clean coffee kg/ha)					Over yearmean
	2015/16	2016/17	2017/18	2018/19	2019/20	
100% DCH	1008.7	1663.5	1665.4	243.3	2536.7	1861.5
100% NP	1143.2	1725.7	2049.7	2176.7	2216.7	1862.4
100% NP + 25% RDCH	1228.1	2104.5	2049.7	2293.3	2303.3	1943.5
75% NP + 50%RDCH	1118.4	1861.0[c]	1788.0	2376.7	2380.0	1924.4
50% NP +50% RDCH	1021.1	1563.3	1911.1	2733.3	2800.0	2083.5
50% NP + 75% RDCH	800.7	1232.1	2299.8	2066.7	2150.0	1624.4
25% NP+ 75% RDCH	1235.7	1956.4	1872.5	2233.3	2133.3	1898.8
25% NP+ 100% RDCH	1125.6	1774.4	1935.4	1766.7	1753.3	17.11.4
Control (without fertilizer)	757.4	1693.5	2136.9	1583.[e]	1656.7	1570..5
LSD (0.05)	199.9	266.7	275.1	307.4	410.1	126.9
CV (%)	11.01	8.91	8.03	8.13	10.71	9.55

DCH = Recommended decomposed coffee husk (10 ton ha^{-1} or 4 kg tree^{-1} on dry weight base) and. Source: [20].

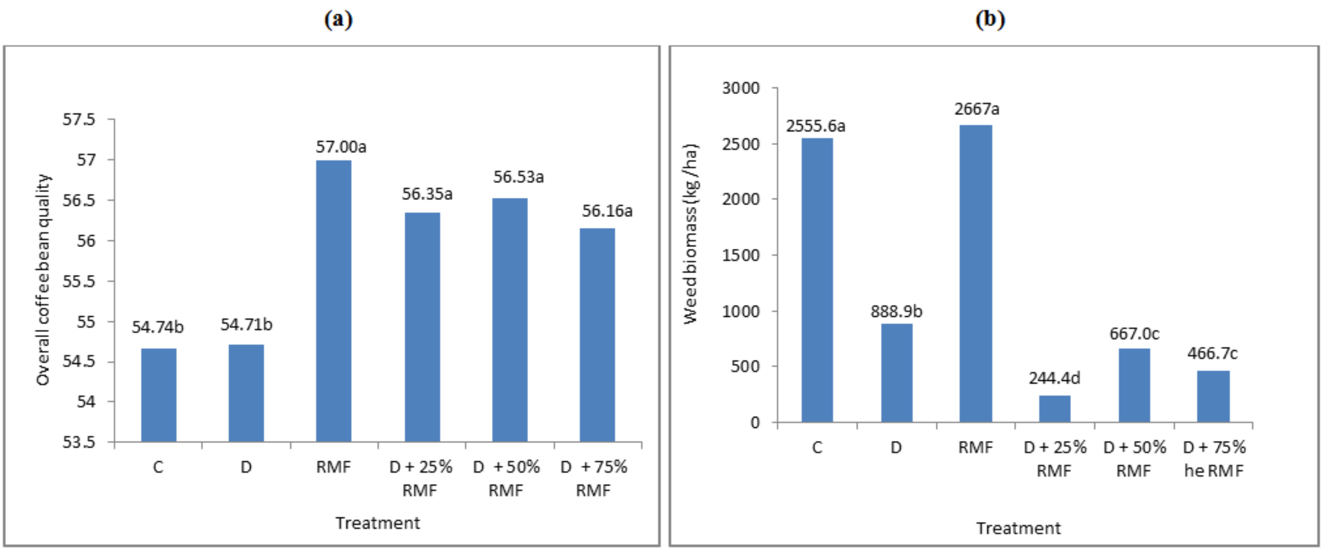

Figure 7. *Effects of Desmodium and mineral fertilizer on overall bean quality (a) and weed biomass (b) at Jimma. Bars capped with same letter are not significantly different at P = 0.01 probability level. C = Control, D = Desmodium. Source: [19].*

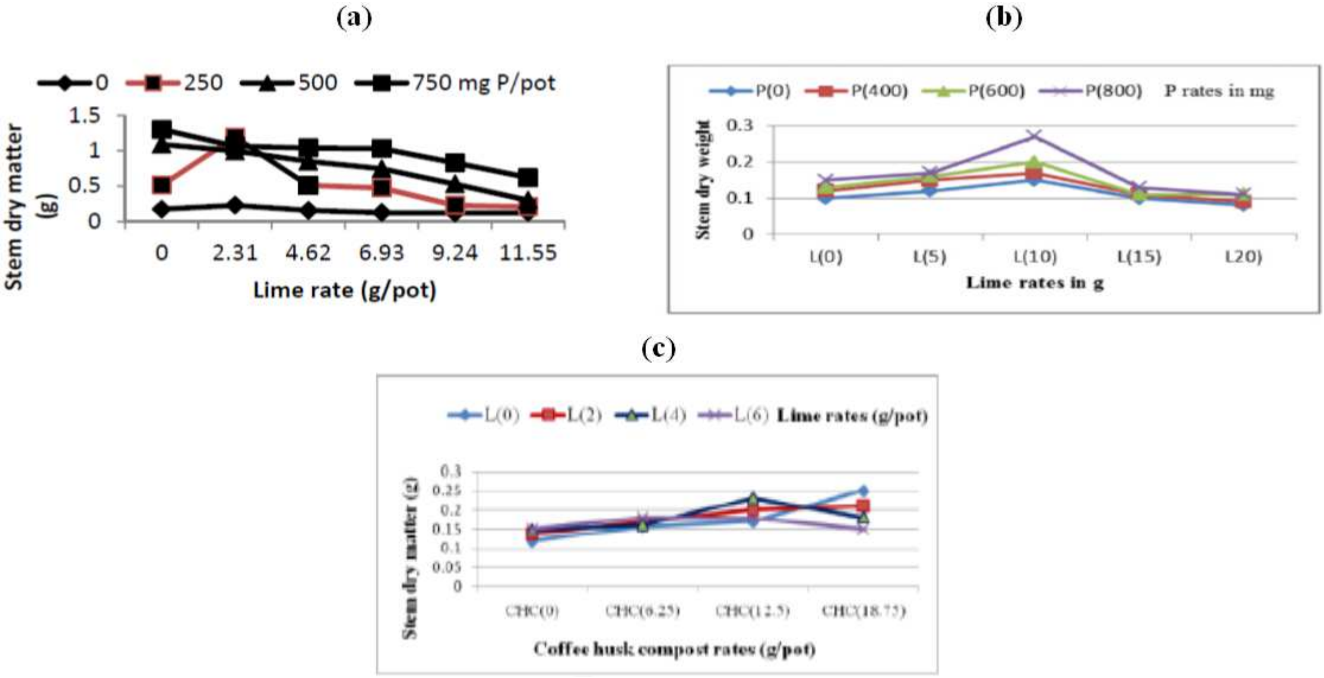

Figure 8. *The effects of lime and P interaction and lime and decomposed coffee husk rates on the stem dry weight of coffee seedlings at Jimma (a and b) and Haru (c). Source: {1, 8, 9].*

Table 13. *Effects of Desmodium and mineral fertilizer on yield (kg ha^{-1}) of coffee at Jimma.*

Treatment	**Cropping season**				**Over years mean clean**	**% yield increase over**
	2016/17	**2017/18**	**2018/19**	**2019/20**	**coffee yield (kg ha^{-1})**	**the control**
Control	520.3c	929.4b	590.4	354.3d	598.6b	-
D	673.0bc	960.2b	892.7	780.7c	826.6bb	38.01
RMF‡	1339.7a	1614.2a	918.5	1231.9ab	1276.1a	113.18
D· + 25% MF	896.7bac	1028.5b	1079.2	1122.7bc	1031.8ab	72.34
D+ 50%RMF	1134.3ba	1495.3a	1204.5	913.4bc	1186.9a	98.28
D+ 75%RMF	749.0bc	1269.4ba	770.4	1574.0a	1090.7ab	82.21
F-test	*	*	NS	**	**	
SE (±)	54.09	45.42	72.48	78.02	32.47	
CV (%)	33.7	20.6	44.1	20.20	16.87	

NS = Not significant, * and ** = Statistically significant at 0.05 and 0.01 probability level, respectively. Figures within a column followed by same letter(s) arestatically not significant at 0.05 probability level. D= Desmodium. Source: [19].

Table 14. *Economic analysis of Arabica coffee yield as influenced by Desmodium and mineral fertilizer at Jimma.*

Treatment	Unadjusted yield (kg ha-1)	Adjusted yield (kg ha^{-1})	Total benefit (Birr ha^{-1})	Total cost that varies	Net benefit (Birr ha-1)	MRR (%)
Control	598.6	538.7	35015.5	0	35015.5	0
Desmodium	826.6	743.9	48353.5	0	48353.5	0
RMF	1276.1	1148.5	74652.5	12708.6	61943.9	241.9
Desmodium + 25% of the RMF	1031.8	928.6	60359.0	3177.2	57181.8	277.9
Desmodium+ 50%of the RMF	1186.9	1068.2	69422.0	6354.4	63067.6	185.3
Desmodium+ 75%of the RMF	1090.7	981.6	63804.0	9531.6	54272.4	

40.00 Ethiopian Birr (ETB) = 1.00 US Dollar. Field prices of clean coffee bean, TSP andureavalued with respective prices of 65.00, 13.50 and 12.68 ETB kg^{-1}. ND = Non dominated and D = Dominated. Source: [19].

3.4. Soil Heath Management Research

3.4.1. Integrated Application of Lime and Phosphorus Mineral Fertilizer

At Jima, nursery pot amended with 750 mg P pot^{-1} (2.5 kg soil), 2.31 g lime + 250 mg P pot^{-1}, and 10 g lime + 800 mg P pot^{-1} produced coffee selection and hybrid seedlings with the highest dry matter (Figure 8).

3.4.2. Integrated Application of Lime and Decomposed Coffee Husk

An amendment containing 18.75 g pot^{-1} DCH, 4 g pot^{-1} lime, and 12.5 g pot^{-1} DCH was a promising amendment for acid soil management and the production of vigorous coffee seedlings for field planting at Haru (Figure 8(c)). This was primarily due to an increase in soil pH and precipitation of exchangeable Al, which fixes P, as well as an increase in soil P solubility and availability to seedlings [1].

4. Conclusion

Coffee pulp and husk composted in a composting pile with organic materials added produced nationally high-quality compost in three months’ time. Compost heaps were suggested as an alternative to pits for preparation. The addition of coffee pulp compost and top soil to potting media improves coffee seedling growth. Furthermore, when decomposed coffee husk compost is used alone or in conjunction with mineral fertilizers, coffee yield increases. Disintegrated coffee husk outperformed *Sesbaniasesban* in terms of improving Arabica coffee production performance. Organic fertilizer may be able to replace chemical fertilizer for the country's resource-constrained coffee farmers. An integrated application of mineral fertilizer and *Desmodium* spp. (green manure crop) can be used as an alternative to mineral fertilizer for long-term soil fertility amendment and promotion of organic coffee production. Organic resources are used at rates of 5 to 10 ton ha-1 (2 to 4 kg tree-1 in dry weight base) and an equal percentage of soil incorporation and surface application techniques are increased coffee output. Soil acidity is a problem in the country's coffee-growing regions. As a result, enriching nursery medium with a combination of lime, P mineral fertilizer, and compost may be a viable alternative amendment for acid soil management and the production of robust coffee seedlings for field planting.

5. Future Research Directions

Several released coffee genotypes are now available for users, each of which may respond differently to mineral nutrition or have different requirements. As a result, the current task is to update or recalibrate the fertilizer recommendations that are already in place for both classic coffee varieties and newly released coffee hybrids and selections. It is known that, not only the amount of fertilizer applied but also its management is also thoroughly investigated for increasing the productivity and fertilizer use efficiency co coffee trees. Among the high priority areas that require attention and further research investigation are studies on the evaluation of alternative organic inputs, frequency of application in relation to soil and climatic conditions, and long-term effects on soil physicochemical properties, weed growth, coffee quality attributes, and economic benefits. Furthermore, action-oriented research activities in the areas of inorganic fertilizer management, integrated nutrient management, and soil erosion control are to be developed. Soil acidity and low soil nutrient these agricultural inputs for the crop's long-term levels, particularly N and P, remained issues for the research system and development efforts in the major coffee-growing regions of the country. As a result, field research should be conducted to evaluate the growth and yield response of coffee trees, as well as the row and cup quality of green beans, to varying levels of lime, P fertilizer, and compost, in order to determine profitable levels of production in the country.

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