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Review Article

Influences of Salient Agronomic Practices for Mitigation of Biennial Bearing in Coffee (*Coffea arabica* L.)

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Abstract: *Coffea arabica* L. is a perennial cash crop which is highly affected by biennial bearing. Most of the time, agronomic practices are applied with the objectives of boosting coffee productivity and production. But very less emphasis on their role of mitigating coffee yield bienniality. Most literatures and scholars didn't clearly and directly indicate the significance of agronomic practices in diminishing oscillation productivity of Arabica coffee. Thus, this review was conducted to assess the importance of salient agronomic practices in alleviating biennial bearing of Arabica coffee and to identify the existing gap by generating biennial intensity analysis from different findings. Salient agronomic practices such as fertilizer application, cover crop, shade, plant density and pruning methods were articulated in this article. These practices contributed in increasing productivity and mitigating bienniality via improving physiological jeopardize agents such as branch die-back, profuse flower bud, plant nutrient, over bearing of berries and rapid exhaustion of productivity parts and environmental stress. It was elucidated that sole field management was less efficient for biennial bearing mitigation than integrated management practices. The integrated agronomic practices that boost coffee yield need to be supported by non-biennial bearing variety for complete abolish of bienniality. Currently, there is no non-biennial bearing Arabica coffee variety. Thus, coffee genetic improvement for bienniality is highly recommended in future coffee breeding program.

Keywords: Agronomic Practices, Bienniality, *Coffea arabica* L., Integrated and Productivity

1. Introduction

Perennial crops' production affected by different factors which are manageable and irrepressible. Once established, they persist for long years giving yield [1, 2]. Commencement from planting up to their senescence stage, their growth and performance in economic traits influenced by different scenarios of endogenic and extraneous factors such as climate change, disease, insect pest and edaphic problems [3]. These may cause genetic erosion, yield reduction or fluctuation [4] and quality lose which totally result food security problem in the world if not solved scientifically.

Alternate bearing is one of the most complex and principal problem in perennial crop production. Many fruit trees and other horticultural crops' production reduced due to biennial effects. For instance, Mango, Apple, Pear, Apricot and Avocado are highly affected by bienniality [5-7]; but, Grape biennial bearing is negligible [8].

Arabica coffee is one of the most affected cash crop by bienniality in the world including Ethiopia. As a result of this, the *Coffea arabica* L. yield is fluctuating or higher one year and lower the next [9, 7]; this of course affects farmers' annual incomes [10]. The intermittent of harvesting coffee yield consequences food security problem especially in developing countries which relied on coffee production. Also, the producers' on and off harvesting affect total coffee production which disturb supply and demand in the world market [10]. Currently, the oscillation of Arabica coffee production became bottleneck for world's coffee industries.

In yield biennial pattern, over load of berries cropping year followed by very low yield bearing season. Over bearing of berries affects coffee quality via lessening fruit size and

disturbing physiological process [11] during fruit development and physiological maturity. Also, the break of branches and disease severity such as coffee leaf rust is serious during on year [5]; heavy crop results branch-dieback [12] which leads to biennial production cycle [11]. Additionally, by the depletion of the reserves of assimilation in on year [13], the coffee trees may be exposed to jeopardize such as complete death. Thus, focus need to be taken to apply appropriate agronomic practices and to develop null in yield biennial coffee variety for mitigation of biennial bearing and production.

Biennial bearing cycle in *Coffea arabica* L. can be emanates from growth and fruit habit itself, environmental factors and management practices (shade, stumping and fertilization) [14, 15]. Arabica coffee exhibits biennial growth and allocate photosynthetic product to fruit formation and growth during year of high production and vegetative growth during years of low production. Shade and pruning alleviate the biennial problem via avoiding overbearing [11] and encouraging renewing bearing surface or growing productive lateral branches that enable producing fruit respectively [16]. Montoya and Umana [17] found reduction of branch die-back to 66% using 200g N per plant in relation to coffee trees to which no N fertilizer applied; this treatment directly reduces yield bienniality. Thus, in addition to developing regular bearing variety, mitigating biennial bearing by management practices is highly momentous in order to frequently harvesting yield from high yielder variety that has biennality nature. Sustainable coffee yield harvest using integrated technologies is decisive to generates continues annual income for producers which contributes in realizing food security; also, it solves unbalanced supply and demand problem in the world coffee industry. Therefore, in the current situation many agronomic practices are underutilization in huge coffee farming for increasing coffee productivity and production; but there is less understanding on their advantage for combating biennial bearing in Arabica coffee. Most findings and articles emphasis and reported the role of agronomic practices on increasing coffee productivity and production and climate change resilience than their direct and/or indirect contribution in biennial bearing mitigation. Their role in alleviating alternate bearing of Arabica coffee is not clearly and directly indicated in many literatures. Thus, the current review conducted with the intension to know the significance of salient agronomic practices in biennial bearing alleviation and to identify the gap for mitigating alternate bearing of Arabica coffee.

2. Agronomic Practices for Alleviating Bienniality in Arabica Coffee

2.1. Population Density

In Ethiopia, the recommended coffee population density and most widely practiced by farms or users is 2500 trees ha^{-1}; But most of the world's coffee producers plant less than 2000 tree ha^{-1} [11]. Numerous findings authenticated that closely planting coffee trees is more preferable than planting with high spacing [18, 19]; but the canopy nature has to be taken in to consideration. The densely planted coffee productivity is higher than that of traditional panting [11]. Also, Pereira et al. [20] and Silveira et al. [21] reported that closer planting increases Arabica coffee productivity.

Plantation of high population density is one of the most important agronomic practice which is highly applicable for compact growth habit coffee varieties/cultivars. This practice presents lower production per plant, but increase production per area [22]. It reduces coffee productivity fluctuation by lessening stress to coffee plant; it enhances more leaf growth, provides suitable microclimate via decreasing air temperature inside coffee trees relative to external environment [22]. Additionally, due to high mutual shading, dense planting decreases over floral initiation, heavy bearing and branch die-back [11] which are important in mitigation of biennial production cycle.

2.2. Integrated Spacing with Pruning Methods

Plant space directly related to population density; it increases or decreases the interior between coffee trees and between rows. Applying closer space planting coffee trees or high density can upsurge productivity per area [22- 24]. Integrating such agronomic practice with pruning methods boost coffee productivity and production [25]. Agronomic practice such as pruning encourage new branch growth and new flower bud formation on newly grown branches [25] which is important in alleviating alternate bearing; also, it helps continuous yield harvest by removing criss-cross and unproductive branch, lean, lanky and whippy wood. These activities are very important to generate uninterrupted income for smallholder farmers and other coffee producers. Coffee productivity and production fluctuation affect growers sustainable income and disturb world coffee industry. The integrated agronomic practices such as spacing and pruning methods improve on and off bearing of Arabica coffee. Coffee trees treated with treatments seven (T7) reduced biennial intensity below 0.1 (Figure 1B) and it gave the highest yield next to treatment three (T3).

Also, despite low yield recorded in treatments (T1, T4 and T5), the biennial bearing was managed to almost null or negligible level. The highest yield was harvested from plots of T3 that planted 62×62 consisting 2652 coffee plants and treated by training on single stem with multiple stems on middle plant (Figure 1A). In agreement, the closer spacing lead to high trees density which enhances production increment per unit areas [24, 26]. But high on and off in bearing or high yield fluctuation observed in plot treated by T3 (Figure 1B). This pointed out field management systems need to be integrated with the genetically improved technology viz non-biennial bearing coffee variety. Mansood et al. [27] confirmed the importance of regular bearing variety to overcome bienniality in Pistachio fruit.

Sole spacing is not effective in mitigation of biennial bearing in Arabica coffee (Figure 2). From pooled yield of over five seasons, the biennial intensity recorded from 0.23 to

0.46. Likewise, Luiz and Aledir [28] reported that high yield fluctuation across years using four different spacing without integrate use of other field practices. Thus, the highest biennial intensity (0.46) observed from closer spacing (1m×0.5m); but the highest yield was recorded across harvesting and over five years mean yield for this treatment. In contrast, Gokavi et al. [25] obtained biennial intensity less than 0.1 using combined spacing with four pruning methods. Hence, using integrated agronomic practices are more efficient in managing or minimizing yield biennial intensity relative to sole agronomic practice.

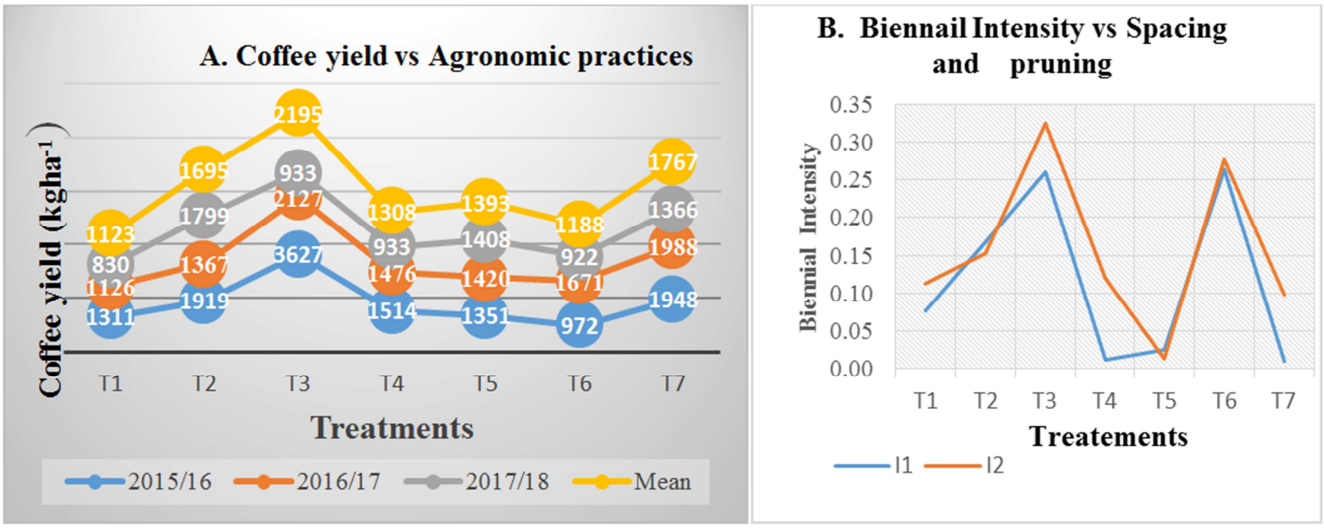

Figure 1. *Influence of agronomic practices (Spacing and Pruning methods) on Yield and Biennial bearing.*

Source: Gokavi et al. [25]

T1 -Square system of planting (62×62) + training on single stem + regular light pruning (Control) (1210 plants acre-1), T2 -Square system at close spacing (52×52) + training on single stem + Rock-n-roll pruning of alternate rows once 3-4 crops (1742 plants acre-1), T3- Square system of planting (62×62 Quincunx) + training on single stem + multiple stem on middle plant (2652 plants acre-1), T4 -Square system at close spacing (52×52) + training on multiple stem without topping + cyclic pruning after each harvest (1742 plants acre-1), T5- Hedge row system on single stem (62×32) + Rock-n-roll pruning of alternate rows (2420 plants acre-1), T6- Hedge row system on multiple stem without topping (62×32) + Cyclic pruning after each harvest (2420 plants acre-1), T7- Paired row system 62×32×72 for tall Arabica + single stem training + Rock-n-roll pruning alternate rows (1452 plants acre-1)

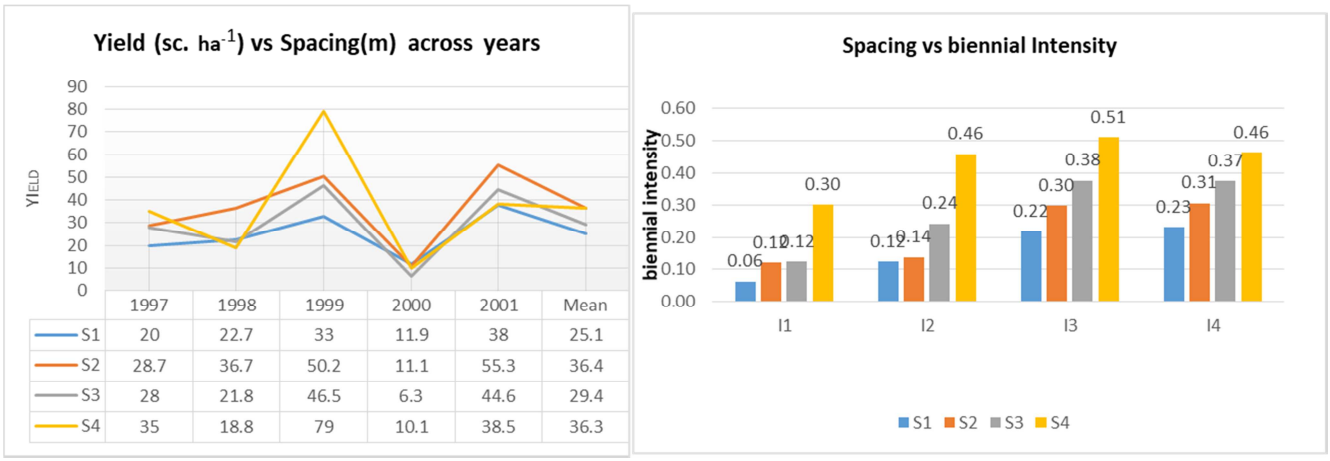

Figure 2. *Role of spacing alone in alleviation of biennial bearing.*

S- Represent spacing, S1- 3m×1m, S2- 2m×1m, S3- 2m×0.5m, S4- 1m×0.5m, I1-I4 –represent biennial intensity over two years, three years, four years and five years respectively; Source: Luiz and Aledir [28]

2.3. Integrated Number of Stems Per Plant with Pruning Methods

Science the commencement of research on increasing coffee yield, agronomist and breeders have been doing many field management practices and genetic improvement respectively. Fostering the growth of one or more number of stem per plant is among the prominent agronomic practices for coffee productivity increment. Integrated pruning with number of stem per plant is practiced for increasing coffee yield [29] like other field management activities. Across five harvesting seasons, yield discrepancy revealed although

different from joined treatments to treatments (Figure 3A). From the joint use of pruning with stem number, biennial intensity could be reduced to 0.07 and 0.15 for T2 and T3 respectively (Figure 3B). The highest yield was recorded by T4 and T5 next to T6 respectively. However, the biennial bearing ranged from 0.26 to 0.33 observed in these treatments. For efficiently diminishes of bienniality problem, applying the joint compatible coffee management practices with regular bearing coffee variety is crucial.

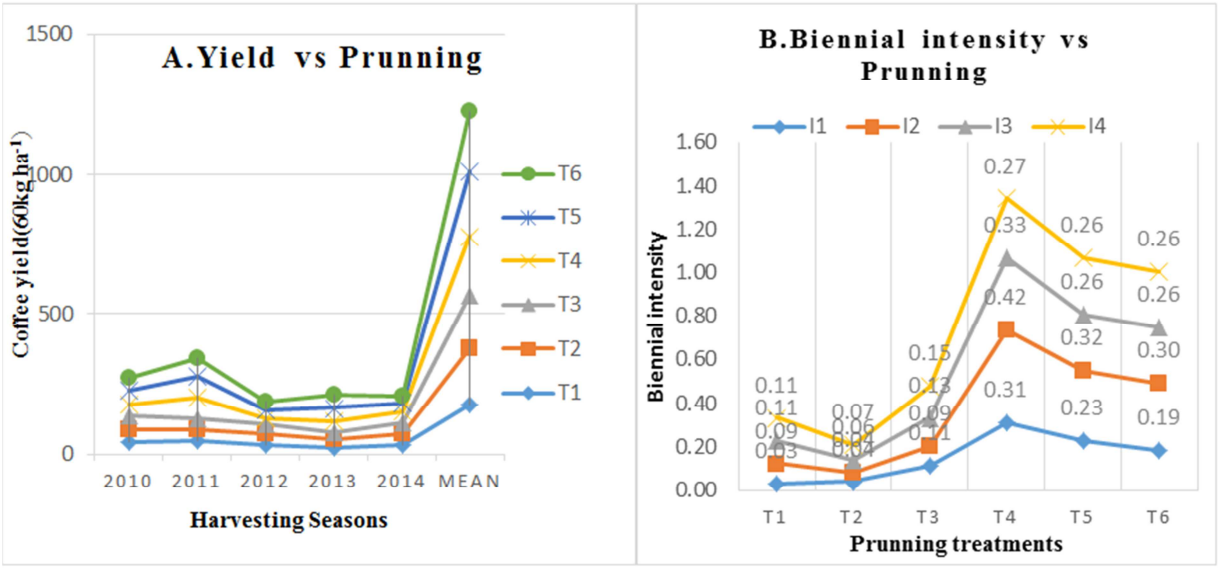

Figure 3. *Combined Pruning methods with number of stems for biennial bearing improvement.*

T1- Traditional pruning without removal of reproductive branches with 2 stems number per plant, T2- CPPAC with removal of 70% of reproductive branches that produced in the season with 2 stems number per plant, T3- CPPAC with removal of 50% of reproductive branches that produced in the season with 2 stems number per plant, T4- Traditional pruning without removal of reproductive branches with 3 stems number per plant, T5- CPPAC with removal of 70% of reproductive branches that produced in the season with 3 stems number per plant, T6- CPPAC with removal of 50% of reproductive branches that produced in the season with 3 stems number per plant. Source: Verdin Filho et al. [29]

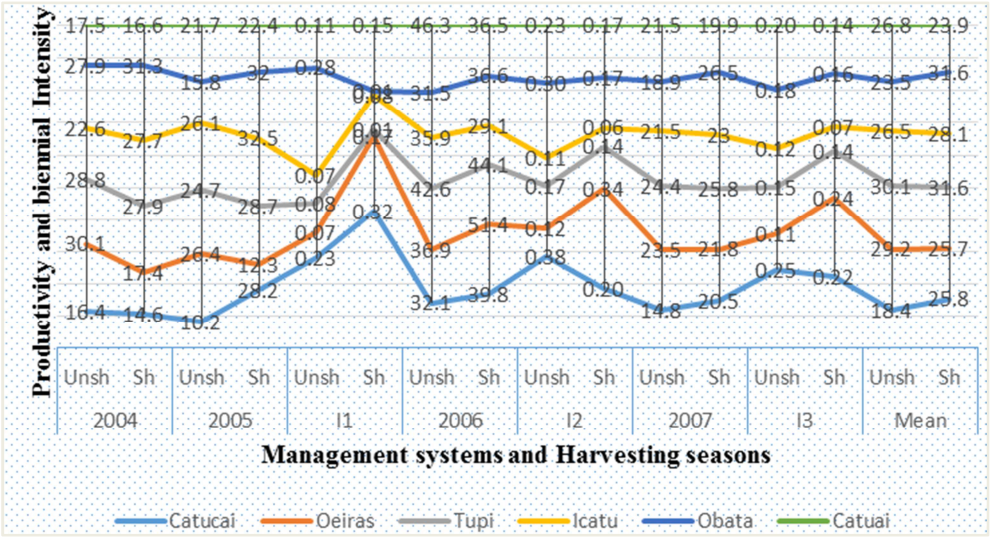

Figure 4. *Coffee productivity (60kg ha^{-1}) and biennial bearing Intensity from 2004 to 2007.*

Unsh: Unshaded, Sh: Shaded, I1-I3: Biennial intensity of two years, three years and four years; shade materials: Banana (*Musa sp.)* and coral bean plants (*Erythrina verna*), Source: Marta et al. [36]

2.4. Shade and Unshaded in Mitigation of Bienniality

Coffee production under shade has great importance for biodiversity conservation and buffering climate change [30 -32]. In addition to this, shade increases the longevity productivity of Arabica coffee and improve climate condition for coffee plant, improve soil condition and lower nutrient demand [33-35]. Hence, shade affects in multi-direction on mitigation of oscillation production. The significant of shade over unshaded in reducing biennially is not revealed during

early seasons (I1) (Figure 4); but, the difference between management systems in reducing the level of bienniality observed in late harvesting seasons [36]. In agreement, Jaramillo-Botero et al. [1] confirmed that the effects of shade on yield fluctuation reduction is after the age of high yielding. Thus, importance of shade over unshaded in mitigation of biennial bearing was manifested from over three (I2) and four (I3) harvesting seasons (Figure 4). This may be due to shade gradual contributions in edaphic characteristics improvement [36-40] and its positive impacts in counterbalance the fruit bearing potential during on and off seasons [41].

The highest influence of yield bienniality revealed on unshaded coffee trees [1]. Shade enhances coffee vegetative growth aspect such as increase number of primary and secondary branches [9] and reduces branch die-back and drying of coffee branches [11, 42] which increase the potential productivity of coffee trees [36]. These phenomena have role in mitigation of biennial bearing by fostering new vegetative growth and generating flower bud of fruit on newly grown branches. Over shade decrease node number and coffee yield per area due to photosynthetically active radiation limitation [43-45]; but lessen yield biennial pattern relative to unshaded [1, 46] and has positive contribution in lengthen the age of productivity. Very low bienniality doesn't mean high yield [1]; but there is steady yield harvesting by producers when compared with complete biennial bearing.

2.5. Fertilizer Application for Biennial Bearing Reduction

Appling fertilizer is another significant practices for sustainable coffee yield harvesting. Especially during on year/over bearing seasons high sink than source may be expected; this may expose coffee trees to different stress such as disease and dieback if not treated well. In such condition, following over bearing season, coffee tree's yield extremely decreased and it allows nutrient recovery and necessary growth causing biennial pattern [1]. Also, high load of berries causes for coffee trees exhaustion which may results complete drying of the trees. Thus, application of required level of fertilize protect such coffee tree from stress damage and exhaustion. Similarly, coffee tree requires high fertilizer after the beginning of high yield or high load berries stage [11]. Appropriate management of coffee trees using fertilizer reduces threat of highly necking and other physiological jeopardize, and it enhances yield bearing with less fluctuations. The use of 40% recommended fertilization for 48% shaded or photosynthetically active radiation blockage has better contributions in alternate bearing mitigation relative to 0% or unshaded coffee plots [1, 9].

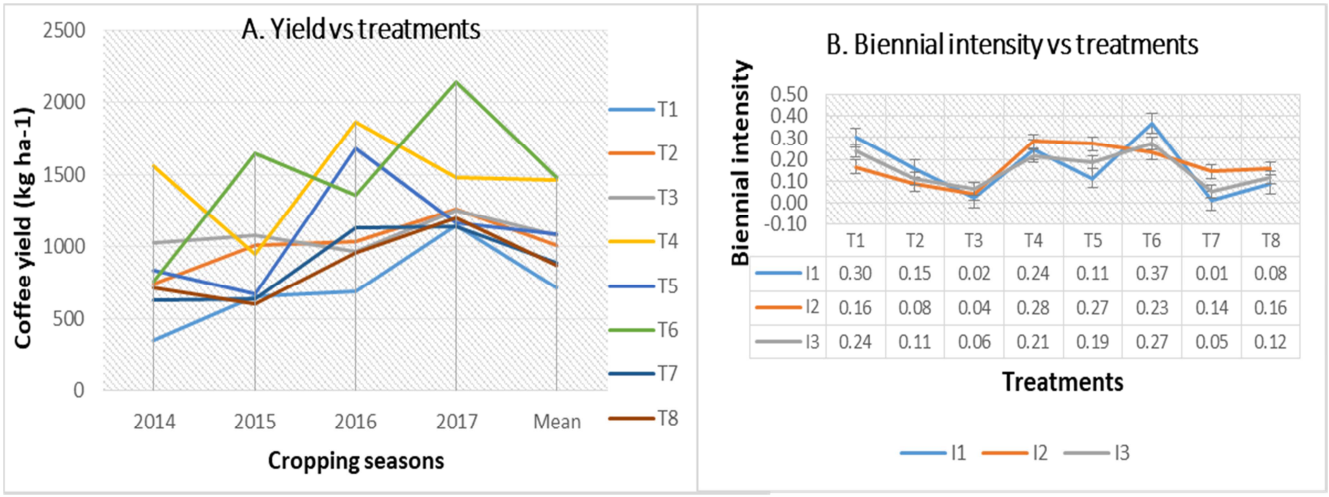

Figure 5. *Role of Integrated weed management on coffee yield.*

T1-One slash in May + one slash in August, T2- One slash in May followed by one slash in July and one slash in August, T3- Herbicide in may followed one slash in July followed by mulch in September, T3- Herbicide in May soybean intercropping in June followed by mulch in September, T4- Herbicide in May followed by common bean intercropping in June followed by mulching in September, T5- Desmodium cover crop, T6- Vetch cover crop in June followed with one hand weeding, T7- Weed free. I1-I3 –represent biennial intensity of over two, three and four years respectively, Source: JARC [49]

2.6. Effects of Cover Crop in Alleviation of Biennial Bearing

Desmodium is one of the most important cover crop that has multi-function. It is highly important in coffee field/farm management practice for weed suppression, improve soil structure and increase soil fertility via fixing nitrogen. Also, it is one of the momentous practices for preventing infestation of coffee wilt disease (CWD) from coffee farm via avoiding the agent such as slashing for weed control. Coffee is a perennial crop and grow slowly; the space between coffee trees and rows is wide and remain open for quit long seasons [47]; this encourages frequent growth of weed which seriously strive coffee for resource and leads decrease in productivity and production. Competitive weed can cause yield loss which reach up 65% to complete failure of coffee trees depending on types of weeds and coffee growth stage [48]. JARC [49] reported weed control efficiency of desmodium is 91.1%,

87.5% and 100% for second, third and fourth coffee harvesting seasons respectively. This may imposes great contributions in coffee production increment and reduces high fluctuation of production due to reduced weed rivalry problem. Treatment 7 (Desmodium) and Treatment 4 (Herbicide+ common bean + mulching) gave the highest yield across seasons and in pooled over four seasons (Figure 5A). Both treatments had reduced biennial bearing intensity of the combined over four seasons (I3) to 0.21 and 0.27 respectively (Figure 5B). Despite their high yielding advantage and lessening bienniality to less than 0.3 (<0. 3), still yield fluctuation observed when compared with the other low yielder treatments. Hence, one has to be conscious to use the desmodium with regular bearing cultivar during production for efficient biennial control. Scholars reported that the importance of integrating non-biennial cultivar with agronomic practices to reduce biennality while increasing productivity [27, 50].

3. Conclusion and Recommendation

Agricultural practices play vital role in resilience abiotic and biotic factors which are hindrance for crop production. Arabica coffee is a perennial crop that needs intensive field managements. Agricultural practices buffer environmental stress and mitigate physiological jeopardize from coffee tree; these have great attribute in boosting coffee productivity and production. In addition to upsurge productivity, they alleviate yield fluctuation from year to year which is essential in realizing food security. Field managements viz shade, population density, fertilizer application and cover crop were discussed in lessening biennial bearing. These practices reduce biennaility by eliminating branch drying, branch die-back, improve soil structure, profuse flower initiation, over bearing and increase longevity of productivity of coffee tress.

The integrated agronomic practices mitigate biennial bearing than sole agronomic practice. Most practices that enhanced high yielding exhibited higher biennial bearing intensity which point out the importance of regular bearing cultivars involvement in mitigation of biennial intensity. For complete bienniality control and yield increment, compatible agronomic practices need to be integrated with non-biennial bearing variety. Thus, it is highly recommended to focus on developing regular yielding variety in the future *Coffea arabica* L. improvement program.

Competing Interests

The authors have declared that no competing interests exist among them.

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