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Influence of Transparent and Black Plastic Mulches and Staking on the Environment, Growth and Yield of Cucumber (*Cucumis Sativus* L) in Abakaliki, Southeastern Nigeria

Aniekwe, N.L.[1], Nwite, P.O.[2]

[1, 2]Department of Crop Production and Landscape Management, Ebonyi State University, Abakaliki, PMB 053, Ebonyi State, Nigeria, 480001

Abstract: ***Amidst the problems of transporting cucumber fruits from Northern Nigeria, its rising demand and its inadequate supply system, an experiment was conducted to investigate the cost effectiveness of producing cucumber in Southeastern Nigeria using the plasticulture technique (plastic sheets) and staking in a 3x3 factorial experiment design replicated four times, covering an area of 276 m^2 in 36 raised flat beds of 2m x 2m manually constructed with West African dwarf hoe in 2010 and 2011 cropping seasons. The growing environment was significantly ($p<0.05$) conditioned by the plastic mulches which raised the average daily soil temperature to 4.38%, income of the farmer to ₦1009.00/plot, produced 11.19 kg of fruits/plot and achieved 100% weed control. Forked-stick stake improved vine length by 2.57%, number of branches by 37.67%, number of leaves by 20.26%, leaf area by 23.11%, number of flowers by 20.18%, number of fruits per plot by 21.15% and fruit weight per plot by 20.63%. Both types of plastic mulches with staking influenced growth and yield of cucumber and improved the environment effectively and can make cucumber production a profitable and sustainable venture among the smallholder farmers, hence, this practice is highly recommended for the smallholder farmers of this farming zone.***

Keywords: Transparent plastic mulch, black plastic mulch, plasticulture technique, plant staking

1. Introduction

The discovery and development of polyethylene polymers in the late 1930s, and its subsequent introduction in the early 1950s in the form of plastic films, mulches and drip-irrigation tubing and tape [21], has revolutionized the commercial production of several vegetable crops under a crop growing system known as plasticulture [22], [29], [40]. The use of these plastic films since its inception as a veritable tool in crop production in the tropical regions has been on the increase [26], [33] as in other regions that require temperature modulation [11]. This management tool has been reported to have offered many benefits ranging from higher yield per hectare, cleaner and higher quality produce, more efficient use of water resources and fertilizer inputs, reduced leaching of fertilizer on light sandy soils, reduced soil and wind erosions, soil compaction, root pruning, better management of certain insect pests [4], reduced disease incidence, and improved micro-climate by modifying the radiation budget (absorbitivity versus reflectivity) of the surface, thereby enhancing earlier crop production and fewer weed problems [8], [14], [21]-[22], [24].

Traditionally, in the early 1960s, impact of colour (black or clear) plastic mulches have been found to be useful tools in modulating soil and air temperatures, moisture retention and energy, showing that the radiating behaviour of mulches depends on their degree of contact with the soil (thermal contact resistance). With air space in-between, soil warming is less effective [9]. Loy *et al.* [25] reported that black plastic mulch raises soil temperature 2.8^{o}C at 2 inches depth and 1.7^{o}C at 4 inches, while transparent plastic mulch transmits 85-95% solar radiation, absorbs very little, and raises day soil temperature 4.4-7.8^{o}C at 2 inches and 3.3-5^{o}C at 4 inches depth compared to bare soil. It is reported that clear plastic mulches were used in solarization (soil sterilization through solar radiation) in the cooler regions [11] of the United States as in the New England States. Solarization is achieved by placing clear plastic mulch over a moist soil for about 30 days of sunny weather which generates enough heat to kill nematodes 5cm to 10cm deep, making the soil, free of living germs [28]). However, one snag with clear plastic films is that it allows weed growth which become killed by intensive heated water droplets that form underneath the mulch. On the other hand, countries in the Middle East, North Africa, high elevations in Southern Africa and other areas of the world with extreme weather conditions use black plastic films to construct protected greenhouses whereas glass is used in Europe and America [33], which enhance production in those countries as expected. Aniekwe *et al.* [2] reported that black plastic films provided a better crop soil environment, 100% weed control, moisture control, raised morning soil temperature to 46% and improved all the growth and yield parameters of cassava significantly, while [3] found that black plastic mulched tilled plots provided superior edaphic environment for cocoyam when compared to other treatments used. In Nicaragua, Mats Gurtner reported that in vermiculture (lombricultura), thick black plastic sheeting is employed to provide shade, maintain an ideal microclimate and give protection from birds [44]. [18] reported the following order of effectiveness: transparent plastic >black plastic >white plastic films in modulating the crop environment.

The production of cucumber fruits in Nigeria is very low due to certain constraints such as finding suitable staking methods that could promote higher yields, mulching and

type of materials used, fertilizers, pests, diseases, and others. Onwueme [31] stated that staked crop plants produced higher yields than unstaked ones. Staking is a cultural practice whereby some materials such as wood, rope or metal are used to provide support for young creeping plants with climbing or straggling growth habit [17], [39]. More than providing supports, staking is advantageous in fruit quality improvement particularly with respect to colour and shape, control of many diseases and insects, high yield per unit area, less damage of vines by trampling, thorough and easy harvesting [7]. Some researchers [20] and [15] reported that staked cucumber produced double yield of fruits than unstaked ones, because of better light penetration and interception. In fact, increased cucumber fruit yield, fruit sizes, reduced fruit rot, easy spraying and harvesting were reported by [32], improved colour and lowered incidence of yellow bellies in cucumber by [34], promotion of seedling recovering and enhancement of fruit soluble solids [42], increased marketable yield [36], uniform lighting of the entire fruit surface, reduced incidence of white belly disorder [23], all these are reported possible benefits of staking. The method of staking crops has a marked effect on the efficiency of crop management and productivity. Methods such as arch training and trellis posts are better than other methods as they expose both the main vine and branches better for fruiting [12].

Most vegetables (fruits, bulbs, roots, etc.) are favourably grown in the Northern states of Nigeria than they are produced in the South because of some environmental and crop management constraints [1]. Transporting these down South from the place of production in non conventional containers leads to damage, rot and high unit cost of the fruits because of high haulage cost. Little experiments here and there in the South show that these constraints can be ameliorated through some specialized cultural practices. It is based on this information therefore, that the objectives of this paper is to investigate the cost effectiveness of producing cucumber in the Southern Nigeria using black and clear plastic mulches and two staking methods. Amidst the transportation problems, the demands for cucumber fruits are increasing geometrically while the supply is always inadequate, hence the need for this experiment.

2. Materials and Methods

Field experiments were carried out in 2010 and 2011 to determine the effects of black and transparent plastic mulches, forked and straight pole stakes on the growth and yield of cucumber in Abakaliki, Southeastern Nigeria. The experimental farm of Ebonyi State University was used for the experiment, located at latitude 06^{o} 19' 407'' N, longitude 08^{o} 07' 831''E and at an altitude of 447m above sea level. The rainfall pattern is in two peak periods with very short break in August (August break) with a total annual rainfall of 1700m-2060mm which concentrates between April and October. The design of the experiment was a 3x3 factorial laid out in a randomized complete block design (RCBD) in four replications covering an area of $276m^2$. Factor A was plastic mulch materials [black plastic mulch (BPM), transparent plastic mulch (TPM) and a control or zero Mulch (ZM)], while factor B was staking methods [forked-stick stake (FSS), straight stick pole stake (SSPS) and unstaked or zero staking(ZS)], which gave rise to nine treatment combinations. A total of 36 raised flat beds of 2m x 2m arising from 9 plots separated by 0.5m per replicate (block) were manually constructed with West African dwarf hoe, while each block was separated by 1m. A blanket application of poultry manure at 20 tons ha^{-1} was applied before the beds were constructed and allowed to stay for two weeks before planting was done. The saucer-shaped leveled flat beds designated by random selection, were covered with the plastic mulches, measuring 2.5m x 2.5m, of which the 0.5m projections were buried in the soil on each sides of the beds to prevent the plastic mulch from been blown away by wind, additional soil was heaped routinely when the soil holding the mulch becomes washed away by rainfall. Prior to planting the seeds, holes large enough to admit the cucumber (marketer) seeds and allow rainfall in were made on the plastic sheets at a spacing of 50cm x 30cm. Common insect pests of cucumber (lady bird beetle and spotted cucumber beetle) were controlled by the application of Endocot 35 EC at the first, third and fifth weeks after planting.

The installation of the stakes was done when the Cucumber vine lengths reached 40cm and were assisted to locate the stakes by leading stakes (little stakes installed near the plant stands to lean on the main stake). Harvesting of fruits commenced six weeks after planting (50-52 days), fourth nightly when the dull green fruit colour turned glossy green to avoid fruit crack and spoilage. Soil temperatures under the mulch treatments during plant growth were taken at 10cm and 15cm depths using soil thermometer in the morning (0700 GMT) and in the evening(1600 GMT) weekly from the first week after planting for five times. Weeds were removed from the unmulched beds regularly as the need to weed arose.

Measurements and data analysis:
Cost of weeding the unmulched beds was calculated, while growth and yield parameters (were taken and statistically analyzed using the analysis of variance (ANOVA) procedure described by [38], while mean separation for detecting significant differences between means was performed using Fisher's least significant difference (F-LSD) as illustrated by [30].

3. Results and Discussion

In Table 1, the transparent plastic mulch (TPM) significantly ($p<0.05$) improved the soil temperature at both depths, in the morning (07.00GMT) and in the evening (16.00GMT) and consequently in the average daily soil temperature, more than the black plastic mulch (BPM) and the zero mulch. Incidentally, the temperature measurements reported here was taken only in the first year of the experiment similar data in the previous year was not significantly different from this experiment taken from the same area. The high soil temperature recorded under TPM agrees with [41] and informs the reason it is used for solarisation. According to [28], clear plastic sheets placed on a moist soil surface and sealed at the sides by burying the edges in the ground on a sunny day raises the temperature at the soil surface to between 40^{o}C - 53^{o}C, 48^{o}C at a depth of 2cm and 30^{o}C at 12cm. At these temperatures growth activities would be

enhanced, and moreover after 30 days of cumulated sunny weather, soil sterilization at a depth of 20cm can be achieved to control nematodes and pathogenic fungi apart from *Fusarium solani*. The average daily temperature under the control was 29.93^{o}C, BPM was 30.64^{o}C, and TPM was as high as 31.30^{o}C, which was probably the reason for the enhanced growth parameters as implicated in the study.

Table 1: Effect of plastic mulches on the morning and evening soil temperatures (^{o}C) of the experimental plots

Mulch	Morning (07.00 GMT)		Evening (16.00 GMT)		Average temperature
	Depth				
	10cm	15cm	10cm	15cm	
ZM	28.70	28.75	31.00	31.00	29.93
TPM	29.80	29.80	32.80	32.80	31.30
BPM	29.42	29.42	31.86	31.86	30.64
Mean	29.31	29.32	31.92	31.92	

Key: ZM = zero mulch, TPM = transparent plastic mulch, BPM = black plastic mulch

On the aspects of weed control, the BPM was very effective in totally suppressing weed growth, whereas TPM allowed weeds to grow but was latter scorched. Comparing the financial implications of controlling weeds manually and using plasticulture techniques showed that it costs higher to apply plasticulture (₦110.00/plot) compared to weeding manually (₦90.00/plot), but the accruable revenue to the farmer was higher (₦1,009.00 afterwards compared to (₦938.00), because more fruit weight/plot was obtained under plasticulture than the manually weeded plots. Other workers [5] and [35] reported that use of plastic mulch increased cost of production, but the net economic returns are also greater. The reduced yield under the zero mulch (10.28 kg/plot) might have resulted from the disturbances made on the plants during weeding (Table 2). This agreed with [27] who observed such reasoning when 13.50 fruits/plot of cucumber was obtained on weeded plots, whereas, 15.50 fruits/plot were obtained on the plots where weeding was not carried out. The importance of this observation is predicated on the fact that manual weeding (hand picking or use of implements) was cheaper, but suppresses yield. The plasticulture techniques incidentally would be more sustainable for the smallholder farmers as the available workforce is dwindling due to strong rural-urban migration of able-bodied youths which can leave the agricultural labour force depleted. Carl Haub who is the senior demographer at the Population Reference Bureau (PRB), said that Africa has the fastest-growing and most youthful population in the world (>20% between the ages of 15-24), who will most likely continue the exodus to cities in search of education and training opportunities, gainful employment and adequate health care [37]. In the final analysis, the revenue accruing to the farmer would sufficiently pay for the cost of supplying plastic mulch, while he saves his energy, produces more fruits (11.19 kg/plot) of better quality, generates more income (₦1,009.00/plot) and maintains the soil in an environmentally-friendly conditions [3]. Also [13] reported cucumber production of 4.6t/ha in Puerto Rico by the use of plastic mulch.

Table 2: Economics of weeding manually and plastic mulch application in cucumber production

Activity	*Plastic mulch*	*Zero mulch*
Cost of weeding/plot @ ₦30.00/plot for 3 schedules	-	90.00
Cost of plastic mulches/plot @ ₦110.00/plot	110.00	-
Weight of fruits harvested/plot (kg)	11.19	10.28
Fruit sales @ ₦100.00/kg	1,119.00	1,028.00
Total revenue accruable to the farmer ₦/plot	1,009	938.00

Plastic mulch significantly ($p<0.05$) influenced all the growth and yield parameters of cucumber measured in this experiment, except in the fruit weight per plot, although the fruit weight obtained in both plastic mulches was higher than the weight from zero mulched plots (Table 3). The transparent plastic mulch appeared to have greater effect than the black plastic mulch on the growth parameters, whereas black plastic mulched plots slightly gave heavier fruit yield than clear mulched plots, but significantly ($p<0.05$) had higher number of fruits (41.00/plot) than the transparent plastic mulch (37.82/plot). This result agrees with [3] who reported that yields were higher in tilled black plastic mulched cocoyam plots when compared to tilled clear plastic mulched plots, no-till black plastic mulched plots and no-till clear plastic mulched plots by 29, 47 and 59%, respectively. The higher average daily temperature (31.30^{o}C) obtained under transparent plastic mulch (Table 1), can explain the high impact it had on the growth parameters, but why not on the yield parameters is not obviously clear. It is logical to expect that high leaf area of 335.22 cm^2 should translate to high yield as it conjures more solar energy and corollary high photosynthesis, except dry matter distribution in cucumber does not follow this logic. Further study on dry matter partitioning may unravel the situation.

Table 3: Effects of plastic mulches on the growth and yield parameters of cucumber

Treatment	Vine length (cm)	No. of branches	No. of leaves	Leaf area (cm^2)	Leaf area Index	Days to 50% anthesis	No. of flowers/ plant	No. of fruits/ plot	Fruit weight/ plot (kg)
BPM	236.84	8.36	127.50	322.98	27.17	34.33	131.75	41.00	11.29
TPM	276.06	8.86	134.84	335.22	30.00	34.42	134.65	37.82	11.09
ZM	221.75	6.29	130.06	312.18	27.35	35.42	108.79	37.08	10.28
F-LSD (p=0.05)	4.64	0.91	1.71	1.09	0.68	0.45	1.82	0.38	1.02

Key: BPM = black plastic mulch, TPM = transparent plastic mulch, ZM = zero mulch

The practice of staking plants significantly ($p<0.05$) improved the growth and yield parameters of cucumber (Table 4). Forked-stick stake had better improvement on all the growth and yield parameters measured than the straight stick pole stake (SSPS) and the zero staking. Forked-stick stake improved vine length by 2.57% over zero stake and

1.14% over the SSPS; number of branches was by 37.67% over zero stake and 35.74% over SSPS; number of leaves was by 20.26% over zero stake; leaf area was by 23.11% over zero stake and 14.81% over SSPS; number of flowers by 20.18% over zero stake and 13.45% over SSPS; number of fruits per plot by 21.15% over the zero stake and 4.96% over SSPS, while fruit weight per plot was improved by 20.63% over zero stake and 2.83% over SSPS. The observation agrees with [1] who reported that staking generally improves the growth and yield of climbing plants and this may be the reason why forked-stick stake effect on the parameters did not show much difference over the straight stick pole stake method. On the other hand, [19] found that trellised cucumber gave greater yield (55%) over the non-trellised ones (45%). It was also observed that staking led to early anthesis (33.58 days) for 50% of the plants per plot to flower in cucumber more than zero stake, while it took SSPS 34.75 days for 50% of the plants per plot to flower. Improved photosynthetic efficiency was also reported to have influenced yield in cucumber [16].

Table 4: Effects of plant staking on the growth and yield parameters of cucumber

Treatment	Vine length (cm)	No. of branches	No. of leaves	Leaf area (cm^2)	Leaf area Index	Days to 50% anthesis	No. of flowers/ plant	No. of fruits/ plot	Fruit weight/ plot (kg)
FSS	247.95	10.38	140.31	362.64	31.26	33.58	140.48	42.17	11.68
SSPS	245.13	6.67	140.21	308.92	27.11	34.75	122.58	40.08	11.35
ZS	241.57	6.47	111.88	278.82	26.14	35.83	112.13	33.25	9.27
F-LSD (p=0.05)	4.64	0.91	1.71	1.09	0.68	0.45	1.82	7.35	1.99

Key: FSS = forked stick stake, SSPS = straight stick pole stake, ZS = zero stake

The application of plastic mulch and staking together assisted in improving days to 50% flowering moderately in cucumber plants as shown in Table 5. This was in agreement with what [10] reported that mulching resulted in earlier flowering and increased yield compared to unmulched plots, which supports our result here. Days to 50% flowering were reduced more in fork-stick staked black and transparent plastic mulched plots (32.75, days) compared to that of zero mulched plots which was delayed to 35.00 days, while straight stick pole staked black and transparent plastic mulched plots moderately delayed flowering to 34. 50 and 34.75 days respectively compared to zero mulched plots that delayed it to 35.25 days. Also, zero staked black and transparent plastic mulched plots delayed flowering much more (35.75 days) than zero staked zero mulched plots (36.00 days). Black and transparent plastic mulch and staking practices in cucumber have proved to be a beneficial cultural practice for the resource-constrained rural farmers in this zone.

Table 5: Effect of plastic mulch and staking interaction on days to 50% anthesis in cucumber

Staking	Plastic mulch			Mean
	BPM	TPM	ZM	
FSS	32.75	32.75	35.00	33.50
SSPS	34.50	34.75	35.25	34.83
ZS	35.75	35.75	36.00	35.83
Mean	34.33	34.42	35.42	

F-LSD (p=0.05) = 0.45 for comparing two plastic mulch means
= 0.45 for comparing two staking means
= 0.29 for comparing plastic mulch and staking interaction means

The effect of black and transparent plastic mulch and staking interaction on vine length in cucumber is presented in Table 6. The longest vine length (289.32 cm) was obtained in fork-stick staked black plastic mulched plots, longer than that obtained in fork-stick staked transparent plastic and zero mulched plots by only 1.80% (284.11 cm) and 14.69% (246.81 cm). The longest vine length was longer than vine lengths obtained in zero staked black and transparent plastic mulched and zero mulched plots by 11.95% for 254.75 cm, 28.20% for 207.73 cm, and 20.37% for 230.40 cm respectively. Vine length obtained in straight stick pole staked black plastic mulched plot (284.11 cm) was longer than that obtained in transparent plastic (217.96 cm) and zero (233.31 cm) mulched plots. Also, zero staked black plastic mulched plot gave higher vine length (254.75 cm) than what was obtained in zero staked transparent plastic (207.73 cm) and zero staked, zero (230.40 cm) mulched plots. The suppression of vine length observed in transparent plastic mulched plots across all the staking methods is not in consonance with the report of [6], [43], that clear and coloured plastic mulches enhanced plant growth, increased vegetable production and earliness.

Table 6: Effect of black and transparent plastic mulch and staking interaction on vine length (cm) in cucumber

Staking	Plastic mulch			Mean
	BPM	TPM	ZM	
FSS	289.32	239.56	246.81	258.56
SSPS	284.11	217.96	233.31	245.13
ZS	254.75	207.73	230.40	230.96
Mean	276.06	221.75	236.84	

F-LSD (p=0.05) = 4.64 for comparing two mulch means
= 4.64 for comparing two staking means
= 2.68 for comparing mulch and staking interaction means

4. Conclusion

Plasticulture, the use of polyethylene polymer films as plastic mulch, drip-irrigation tubing and tape, and staking practice is helping in a great way in modernizing agricultural activities, reducing tedium and making farming somewhat attractive to the migrating youths. Literature is rife with the numerous benefits plasticulture offers to those farmers who employ the technique in their farming activities. Those benefits include: earlier harvest, reduced evaporation, fewer weed problems, reduced fertilizer leaching, reduced soil compaction, increased growth, cleaner produce, control of water logging on the soil surface, assists in insect and disease management, greater economic returns, and more, as implicated in this our work. However, the major snag with this technique is removal and disposal problems coupled

with the initial high cost of procuring the material. It is interesting to note that some research effort is now addressing this problem, and some new photodegradable and biodegradable films have been developed. This disposal issue is being vigorously debated by the plastic industries, university scientists and agricultural producers such as the American Society of Plasticulture, which has formed a plastic disposal committee to investigate recycling and energy reclamation of agricultural plastics [25]. Staking also contributed in no small measure to the enhancement of growth and yield of cucumber and other crops too as we indicated in this report, such as improved fruit quality, less damage vines, more thorough harvesting, yield increase, ease of work in the farm, ease of insect and disease management and more. These benefits however, did not exclude the extra cost of sourcing and transporting the stakes, cost of erecting, dismantling and removal, the labour expended in installing lead-stakes and directing the vines to the lead-stakes. Despite all this, plastic mulching and staking are good cultural practices that could promote cucumber production in this zone, hence, highly recommended for sustainable cucumber production in southeastern Nigeria.

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